MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

Volume 117 No. 3 1957

ANNUAL REPORT OF THE COUNCIL

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ROYAL ASTRONOMICAL SOCIETY

Founded 1820

ANNOUNCEMENT OF NEW PUBLICATION

First number to appear in 1958 March

The Geophysical Journal

Price (post free): £3 ($9 in U.S.A.) for a volume of at least four parts.

This is a new journal of the Society for the publication of research in geophysics and related subjects. It is being started because the rapid development in geophysics calls for a journal that will appear at short intervals and contain papers covering the wide range of subjects involved. The increase of geophysical activity now makes it essential that authors should be assured of speedy publication and that their work should become known through a large and world-wide circulation.

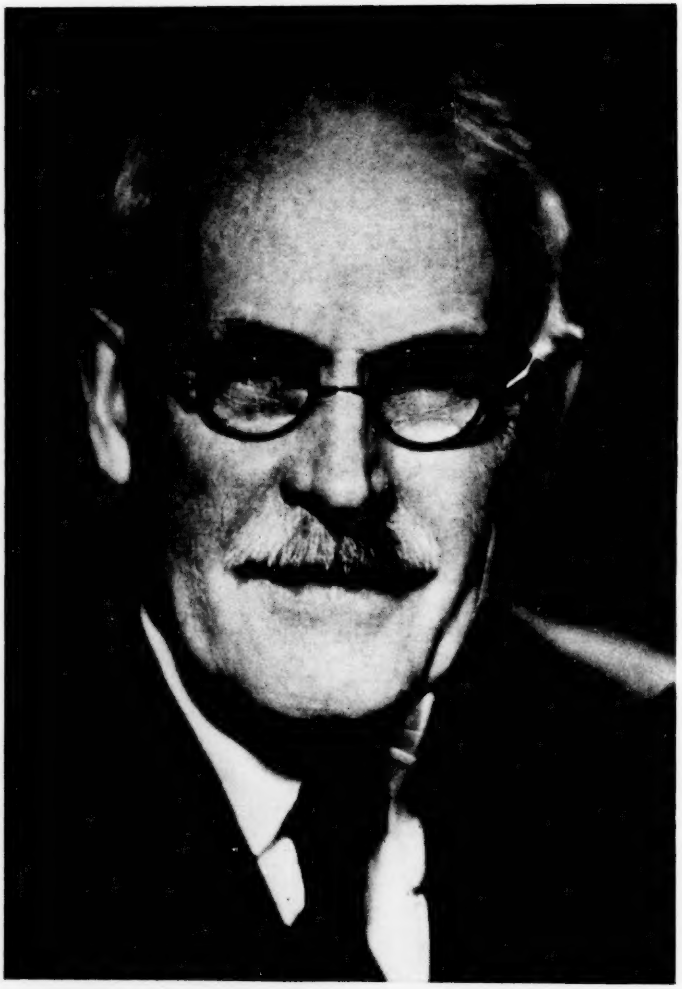
The *Geophysical Journal* will contain original papers, short notes and letters, and articles on the progress of geophysics, together with book reviews and reports of geophysical discussions.

The *Geophysical Supplement* to the *Monthly Notices* of the Society will be incorporated in the new *Journal*. The last number of the *Geophysical Supplement* will appear towards the end of 1957.

The *Geophysical Journal* invites papers of high standard on the topics previously covered by the *Geophysical Supplement* and also on related subjects such as, for instance, some aspects of work on the upper atmosphere. To ensure the minimum of delay between acceptance of a paper and its publication, the *Geophysical Journal* will be issued quarterly. It is hoped that these features, together with the wide circulation enjoyed by the Society's publications, will encourage authors (who need not be Fellows of the Society) to contribute to it.

Papers for publication should be sent to the Assistant Secretary of the Royal Astronomical Society, Burlington House, London, W.1, England.

The *Geophysical Journal* will be edited by A. H. Cook, M.A., Ph.D., F.R.A.S., F.G.S. and T. F. Gaskell, M.A., Ph.D., F.R.A.S. in collaboration with the Geophysical Secretary of the Society, R. A. Lyttleton, M.A., Ph.D., F.R.S.



Professor Sir Harold Jeffreys, F.R.S.
President 1955–1957

MONTHLY NOTICES

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ROYAL ASTRONOMICAL SOCIETY

Vol. 117 No. 3

ANNIVERSARY MEETING OF 1957 FEBRUARY 8

Professor Sir Harold Jeffreys, President, in the Chair

The election by the Council of the following Fellows was duly confirmed :—

Joyce Margaret Blackler, Girton College, Cambridge (proposed by W. H. McCrea); and

John Frederick Richard Divers, Endley-Severals, Springwell Road, Beare Green, Surrey (proposed by H. Bondi).

Seventy-six presents were announced as having been received since the last meeting.

The President gave an address on the award of the Gold Medal to Professor Albrecht Unsöld (see p. 344).

The President gave an address on the award of the Jackson-Gwilt Medal and Gift to Mr R. P. De Kock (see p. 346).

The President then delivered his address on " Probability Theory in Astronomy " (see p. 347).

ANNUAL GENERAL MEETING OF 1957 FEBRUARY 8

Professor Sir Harold Jeffreys, President, in the Chair

The Minutes of the preceding Annual General Meeting were read, confirmed and signed.

The Secretaries, on behalf of the Council, moved the adoption of the following resolution :—

That the following instruments be given to the British Astronomical Association :—

No.	
16	Wollaston $3\frac{1}{2}$-inch telescope with O.G.
22	$3\frac{1}{4}$-inch telescope with O.G. Camera and other parts.
23	Transit Instrument.
30 (S4)	$3\frac{1}{4}$-inch telescope with O.G. and other parts.
31 (S5)	$2\frac{3}{4}$-inch telescope.
36 (S10)	Sextant.
47	Hand sextant with artificial horizon.
123	6-inch telescope (with O.G.).
124	Position micrometer.
125	6-inch telescope with O.G. and other parts.
132	Waters equatorially mounted camera, with stand.
137	Polar siderostat with $4\frac{1}{2}$-inch mirrors.
140	$3\frac{3}{4}$-inch O.G. and tube.
142	Position micrometer with 2 eye-pieces.
159	Telescope tube with mirror and finder.
162	Abney doublet.
172	Dallmeier Rapid Rect. Abney doublet.
A.2	Sextant.
A.10	Camera but no lens. Dark slides.
A.11	Camera box with shutter. No lens.
A.22	Dawes Solar eyepiece.
	Odd stands and drive weights.

After discussion, the resolution was adopted.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year.

The Treasurer gave a brief explanation of the accounts for 1956 and a survey of the Society's financial position.

The Report of the Honorary Auditors was read (see p. 233).

A vote of thanks to the Honorary Auditors of the Treasurer's Accounts for 1956 was proposed and carried unanimously.

It was proposed and carried that the Report of the Council be received and adopted, and that it be printed and circulated in the usual manner, together with the Report of the Honorary Auditors and the President's Address.

The Scrutineers reported to the President the result of the ballot, and the names of the Officers and Council elected for the ensuing year were read to the meeting. (The list of names is given on p. 356.)

The retiring President called upon his successor, Dr. W. H. Steavenson, to take the Chair. He did so amid applause, and expressed his thanks to the Fellows for the honour they had done him.

The thanks of the Society were given to the retiring President (Sir Harold Jeffreys), Vice-Presidents (Dr A. Hunter, Dr J. Jackson, Professor A. C. B. Lovell and Dr R. A. Lyttleton), Secretary (Professor C. W. Allen) and other members of Council.

The thanks of the Meeting were given to the Scrutineers of the ballot.

The meeting then adjourned.

REPORT OF THE COUNCIL TO THE HUNDRED AND THIRTY-SEVENTH ANNUAL GENERAL MEETING OF THE SOCIETY

This Report refers to the calendar year 1956

1. *Publications.*—The most pressing needs of the Society at present are concerned with the speed and economy of publication.

Comparison with other societies has shown that the time that elapses between the receipt of a paper and its final publication in the Society's journals could be substantially reduced. This delay has lately been about a year but could be reduced to six months or even less for papers that do not present any special difficulties. Careful consideration is now being given to all the factors that add to the delay. The proof-reading time has been reduced very considerably by having much more of it done in the Office of the Society. This has been made possible by the appointment at the beginning of 1956 of an Editorial Superintendent. Quicker and more systematic proof-reading is enabling the printer to keep to more regular setting and printing schedules. Attempts are being made to reduce the time during which papers are in the hands of referees. In spite of printing-trade troubles early in 1956, which caused a serious hold-up in all printing, considerable progress in the acceleration of publications has been made and much more progress is in sight.

During the year the following were published and distributed :

Monthly Notices, Vol. **115**, Nos. 2, 3, 4, 5, 6; Vol. **116**, Nos. 1, 2.
Geophysical Supplement, Vol. **7**, Nos. 2, 3.
Memoirs, Vol. **67**, Parts 3, 4.
Occasional Notes, No. 18.

There has been an increase of about 15 per cent in printing costs, and this will place a strain on the economy of the Society. Investigation has shown that there is very little prospect of producing the Society's publications any more cheaply than at present. It would appear that economic improvement must come from a wider distribution or increased payment for our journals. Similar problems have to be faced by other learned societies, and the Royal Society has convened discussions between a number of these with the view to finding a general solution to the problem of reducing publication costs. The Nuffield Foundation has provided funds for a thorough-going investigation of the matter and the Society hopes to gain advantage from these inquiries in due course. In the meantime the Society remains in need of the Grant-in-Aid for Scientific Publications and this year the Royal Society has allotted to our Society the sum of £1,850, which is an increase of £850 over the previous year.

2. *Finance.*—There was a change of Treasurers " in mid stream " during September when Professor L. M. Milne-Thomson retired prior to his departure for America. We thank Professor Milne-Thomson for his vigorous efforts on

our behalf during the last five years. The Society is most fortunate in being able to recruit the enthusiastic services of Dr G. Merton for the new Treasurership.

The Society has continued with the policy of turning its investments into equities. It has been found advisable to make the change-over apply to a rather larger proportion of the Society's funds than the two-thirds previously decided. The initial programme has been completed but further changes will be made when it seems desirable. The investment portfolio has now to be continually watched and this throws a heavy responsibility onto the Treasurer and Finance Committee.

During the year the Society has received a further £404 12*s*. 10*d*. in respect of the Plummer Bequest.

In past years the Society has been able to benefit from those Fellows who have made their annual contributions by covenant. However, as a result of a High Court judgment on 1956 July 11, in the case of another society, the repayment of tax in respect of annual contributions is now being withheld. It is understood that an appeal against this judgment has been lodged but if this is not successful the Society stands to lose about £450 annually. Repayment of £103 has however been made on those special gifts and compounders' donations which are paid under covenant.

The greatest part of the Society's financial turnover is associated with its publications. The main problems have been explained in Section 1. Other expenses are connected with the essential services of the Society and it is not thought that any practicable changes in these could improve the general economy.

The accounts this year have been audited by Messrs. W. B. Keen and Co. Some small changes have been made in their presentation which it is hoped will be agreeable to Fellows.

3. *Membership*.—The membership of the Society continues to increase as it has done since the War at a fairly regular rate of nearly 3 per cent per annum. This is small compared with the 10 per cent which has recently been mentioned as the expected rate of increase in the activities of a modern scientific organization. We would like to see a greater increase rate particularly at a time when there is so great an interest in astronomy. However a society that is 137 years old can hardly expect its regular increase now to be greater than 5 per cent. The membership table for 1956 is to be found on p. 240.

The Society has lost by death the following associates:

Walter Sydney Adams
Gregory A. Shajn

and the following Fellows:

Ivo Francis Henry Carr Carr-Gregg
Clarence Augustus Chant
*Albert Coleman
*Ralph Emerson De Lury
Donald Luther Edwards
*John Evershed
Albert William Francis Hallam
Neal John Heines
*Gerald Ponsonby Lenox-Conyngham
Hector MacPherson
Sydney Briton Henry Manning
Thomas Charles Lansfield
*Percy Mayow Ryves
*Robert J. Trumpler
Cyril Walmesley
*Edmund Taylor Whittaker

* Life Fellow.

Obituary notices of some of these appear on pp. 243–257 together with some others held over from the last Report.

4. *Meetings.*—Eight ordinary meetings were held as usual in Burlington House during the year and also three Geophysical Discussions. In addition, the Society met in Bristol on July 9–10 at the invitation of the Vice-Chancellor and Senate of the University of Bristol. We thank Professor M. H. K. Pryce and Dr W. J. Bates who made the local arrangements for the well-attended meetings and excursions. The public lecture was given by the Astronomer Royal on the Isaac Newton Telescope Proposals.

Astronomers from Overseas who attended the Society's meetings include Professor E. Schatzman (Paris), Professor J. H. Oort (Leiden), Professor Y. Öhman (Stockholm), Dr E. J. Öpik (Armagh), Dr J. H. Piddington (Sydney), Professor H. C. Urey (Chicago) and Mr N. F. Little (New Plymouth, N.Z.).

5. *Awards.*—The Gold Medal for 1956 was awarded to Professor T. G. Cowling for his distinguished contributions to theoretical astrophysics and particularly for his work on the stability of stars.

Three Associates were elected in 1956: Dr J. Bartels, Dr C. Payne-Gaposchkin and Dr C. D. Shane. It will be noticed that, following the discussion mentioned in the last report, the Council has included a prominent geophysicist (Dr Bartels) in its selection.

6. *Premises.*—The seating in the Meeting Room was renewed in January and the new benches are a great improvement.

The room that has for many years been styled the lumber room has been cleared, refurnished and re-named the Isaac Newton Room. It is to be used as a map and chart room and in particular will house the new Palomar Sky Atlas. The revitalizing of this room is another act of generosity to the Society by Mr Jack Miller.

In all matters concerning the maintenance and furnishing of the premises the Society has had valued advice freely given by Mr H. L. Kelly, F.R.I.B.A.

7. *Instruments.*—For many years there has been little use made of the Society's instruments. The reasons are that the instruments are not modern and the Society does not have suitable facilities for handling them. It is thought that those instruments we do possess would be of more value to astronomy if they were handled by an institution that makes a feature of distributing astronomical instruments for observational purposes. Accordingly those of our instruments that are suitable have been sent to the Curator of Instruments of the British Astronomical Association for them to distribute to observing astronomers. The instruments concerned are mainly rather small telescopes, some of which are somewhat incomplete from an astronomer's point of view. In the opinion of Council the instruments should be made over entirely to the B.A.A., otherwise administrative restrictions will prevent their fullest use by observers.

The instruments of the Society that are already in use are mostly on permanent loan to established institutions. Many are historic instruments on loan to museums. What remains are a number of minor items of very doubtful value.

It is thought that the Society should keep very few of these on the permanent lists and the rest should be discarded or distributed among any that may be interested.

8. *Isaac Newton Observatory.*—The Isaac Newton Telescope Committee set up a small Executive Committee, as reported last year. This Executive has met several times during the year and made substantial progress.

9. *The Staff.*—Resignation and sickness have caused some staffing re-arrangements during the year.

Great concern is felt for the Librarian, Mrs M. H. Markiewicz, who has been suffering from a prolonged illness since October 29. Fellows hope for her steady return to health. The Society is fortunate in being able to obtain the services of Miss E. Wadsworth, who has returned from her retirement to take charge of the Library for the present.

On April 1 Miss M. Garratt resigned the position of Assistant Secretary which she had held since 1947 August. A small memento of her work with the Society was presented to her at the October meeting.

Mr E. C. Rubidge has now combined the duties of Editorial Superintendent with those of Assistant Secretary and the Society is greatly indebted to him for shouldering these additional burdens and carrying them out so efficiently, while at the same time devoting his energies untiringly to speeding up the production of the Society's publications.

10. *Representatives of the Society.*—The representation quoted in the report for 1955 requires a correction. The representative of the Society appointed in the year 1955 on the Board of Visitors of the Royal Greenwich Observatory was Dr R. A. Lyttleton (not Professor Bondi). The representative to the same Board appointed in 1956 was Professor H. Bondi.

Further representatives of the Society were appointed during the year as follows:

on the Board of Management of the Isaac Newton Observatory,
Dr W. H. Steavenson; and
on the Court of the University of Exeter,
Professor V. C. A. Ferraro.

REPORT OF THE HONORARY AUDITORS FOR THE YEAR 1956

We have examined the professionally audited accounts of the Society and have checked the official list of Fellows against the subscriptions received. The membership continues to increase; we note with regret a larger number of resignations than is usual.

We have examined the premises of the Society and note with satisfaction:

(1) The maintained standard of general cleanliness, and the well-kept appearance throughout; in particular the clean condition of the Library books and papers.

(2) The completion and furnishing of the Lumber Room, now renamed the Isaac Newton Room and used for storing the Palomar Sky Atlas.

(3) The completion and small augmentation of the bench seating together with the provision of new linoleum in the Meeting Room.

(4) The improved condition of the Instrument Store.

With less satisfaction we note the following:

(5) The dampness and bad decorative order of the Caretaker's Bedroom.

(6) The poor decorative order of the Caretaker's Kitchen.

(7) The very inefficient lighting arrangements in the Secretarial Offices.

(8) The still overfilled condition of the chart case in the Main Library.

(9) The very poor condition of the window frames of the upper staircase.

We strongly recommend that immediate steps be taken to rectify the unsatisfactory conditions in the Caretaker's apartments. We also recommend that priority be given to the rearrangement and possible replacement of the present lighting arrangements in the Secretarial Offices. We suggest that the various maps, charts and photographs, still crushed into inadequate space, be transferred to, and suitably housed in, the Isaac Newton Room.

Finally, we wish to acknowledge the ready assistance given us by the Assistant Secretary throughout the audit.

G. H. A. COLE
E. A. WHITAKER

General Fund Income and Expenditure

1955 £	1955 £	*Expenditure*	£ s. d.	£ s. d.	£ s. d.
		To Publications: printing, etc.			
		Monthly Notices:			
		Vol. 115 (Balance of cost not provided in 1955)	727 19 1		
		Vol. 116, Nos. 1—6*	3,099 5 2		
				3,827 4 3	
		Geophysical Supplement, Vol. 7, Nos 4 and 5 ..		505 8 11	
		Occasional Notes, Vol. 3, No. 19		74 18 4	
		Memoirs, Vol. 67, No. 4		206 10 5	
		Index		196 14 2	
		Paper Supply		466 13 9	
		Miscellaneous printing and carriage		108 19 10	
	5,639			5,386 9 8	
	1,000	*Less* 1956 Parliamentary Grant-in-Aid for Scientific Publications, through the Royal Society		1,850 0 0	
4,639					3,536 9 8
282		„ Postages and Packing			563 1 4
1,824		„ Salaries and Wages, Pension Premiums and National Insurance			2,445 4 1
		„ *General Expenses:*			
	75	Insurance and Telephone		94 5 3	
	99	Stationery and Office Expenses		111 3 11	
	208	Lighting and Heating		300 18 8	
	10	Travelling Expenses		13 10 2	
	4	Subscriptions to National Central Library and A.S.L.I.B.		4 4 0	
	73	Accountants' Fees		63 0 0	
	15	Gold Medal		15 0 1	
	47	Furniture and Fittings, including repairs		... ...	
	11	I.A.U. Telegram Service		4 5 5	
	183	House Expenses		214 12 7	
	59	Meeting Expenses		68 3 2	
	142	Sundries		32 11 6	
926					921 14 9
190		„ Block Subscription to *The Observatory*			215 0 0
293		„ Reproduction of Photographic Slides and Prints ..			132 7 9
22		„ Films, Hire and Expenses			... ...
2		„ Bristol Meeting Expenses			12 14 3
55		„ Conversazione Expenses			... ...
		„ *Library Expenses:*			
	33	Equipment, etc.		36 2 4	
	14	Purchase of Books		13 13 6	
	187	Binding of Periodicals, etc.		121 9 3	
234					171 5 1
600		„ Reserve for Repairs and Maintenance			363 6 3
		„ Excess of Income over Expenditure for the year, transferred to General Fund			83 3 8
£9,067					£8,444 6 10

* Including cost of Nos 4–6, estimated at £1,415 10*s.* 0*d.*

Account for the Year ended 1956 December 31

1955 £	1955 £	Income	£	s.	d.	£	s.	d.	£	s.	d.
		By *Amounts received from Fellows :*									
		Admission Fees :									
		Current Year	130	4	0						
		Arrears	2	2	0						
		Annual Contributions :									
		Current Year	2,815	1	0						
		Arrears	129	3	0						
	2,963					3,076	10	0			
		Deeds of Covenant :									
	471	Income Tax Recovered				...	...	...			
		,, *Composition Fees :*									
	155	Transfer from Reserve Account				147	18	6			
	50	Special Donations from Compounders				250	6	2			
	100	Mr Jack Miller's Benefaction				100	0	0			
3,739									3,574	14	8
	1,197	,, Interest and Dividends (less foreign taxation)				1,241	9	2			
	129	,, Interest on Bank Deposit Accounts				121	8	11			
1,326									1,362	18	1
		,, *Sales of Publications :*									
		Monthly Notices, Vol. 116				1,253	9	2			
		,, ,, Vol. 115				10	7	2			
		,, ,, Vol. 114 and earlier				387	12	5			
		Geophysical Supplement				268	1	11			
		Memoirs, Occasional Notes, and Miscellaneous ..				776	10	6			
		Reprints				312	8	5			
2,486									3,008	9	7
		,, *Miscellaneous Receipts :*									
		Palomar Slides and Prints				178	16	0			
		R.A.S. Slides and Prints				71	4	2			
		Hire of Films				20	10	0			
		British Astronomical Association				168	0	0			
		London Mathematical Society				40	0	0			
		Physical Society				7	2	6			
		Sundries				12	11	10			
672									498	4	6
844		,, *Deficit for the year 1955*							...	...	...
£9,067									£8,444	6	10

Balance Sheet

1955 £		£	s.	d.	£	s.	d.	£	s.	d.
	General Fund:									
	Balance at 1956 January 1				28,357	17	10			
	Add Donation	2	0	0						
	Excess of Income over Expenditure 1956	83	3	8						
					85	3	8			
					28,443	1	6			
	Less Net loss on sale of Investments ..				2,346	9	5			
28,358								26,096	12	1
	Trust Funds:									
	Capital at 1956 January 1				7,459	10	2			
	Plummer Bequest—final distribution ..				404	12	10			
	Income Balances at 1956 December 31 ..				1,974	5	4			
	Income Tax on Trust Funds not yet refunded				18	12	10			
9,374								9,857	1	2
	Arthur Stanley Eddington Commemoration Fund:									
	Balance at 1956 January 1				409	2	6			
	Income Balance at 1956 December 31 ..				56	18	3			
464								466	0	9
106	*Mr Jack Miller's Gift—Palomar Sky Atlas Fund* (see Contra)							...	...	...
	Repairs and Maintenance Reserve:									
	Balance at 1956 January 1				539	7	4			
	Transfer Income and Expenditure Account				363	6	3			
					902	13	7			
	Less Expenditure 1956				602	13	7			
539								300	0	0
	Sale of Discarded Books Fund:									
	Balance at 1956 January 1	2,333	9	1						
	Add Sales 1956	42	15	0						
	Interest 1956	43	14	5						
					2,419	18	6			
	Less Expenditure 1956				125	13	6			
2,333								2,294	5	0
	Composition Fees Reserve Fund:									
	Balance at 1956 January 1	2,433	8	9						
	Received in 1956	32	0	6						
					2,465	9	3			
	Less 6 per cent transferred to Revenue Account				147	18	6			
2,433								2,317	10	9
	Staff Pension Fund:									
	Balance at 1956 January 1	570	4	9						
	Add Interest 1956	14	5	0						
					584	9	9			
	Less Pensions paid				79	17	6			
570								504	12	3
	Benevolent Fund:									
	Balance at 1956 January 1				23	9	4			
	Donation				1	1	0			
24								24	10	4
	Amounts received in Advance:									
192	Contributions				373	18	7			
128	Publications, 1957				147	11	6			
								521	10	1
4,878	Sundry Creditors for accounts due but not presented, including provision for printing publications for 1956 and binding periodicals, not yet completed							5,530	16	10
£49,399								£47,912	19	3

To the Fellows of THE ROYAL ASTRONOMICAL SOCIETY

We have examined the above Balance Sheet and Accounts with the books and vouchers information and explanations given to us. We have verified the Investments, and Balances at which have been inspected by the Society's Honorary Auditors.

FINSBURY CIRCUS HOUSE,
BLOMFIELD STREET, LONDON, E.C.2.
1957 *January* 16.

1956 *December* 31

1955 £		£ s. d.	£ s. d.
	Investments:		
	General Fund, valued as at 1922 December 29 or		
29,800	subsequent cost	32,428 19 5	
7,448	Trust Funds, valued at cost	7,952 15 0	
			40,381 14 5
	Debtors:		
	General	481 9 1	
	Income Tax Recoverable:		
	General Fund	241 13 4	
	Trust Funds	18 12 10	
	Palomar Sky Atlas Fund	42 10 0	
	Payments under Covenant	42 10 0	
572			826 15 3
	Deposits at Savings Banks:		
6,688	General Fund	3,700 0 5	
873	Trust Funds	14 16 1	
			3,714 16 6
	Balance on Current Accounts at Bank and Cash in Hand:		
2,984	General Fund	1,025 7 3	
1,034	Trust Funds	1,870 17 3	
			2,896 4 6
	Fund Overdrawn:		
	Mr Jack Miller's Gift—Palomar Sky Atlas Fund:		
	Balance at 1956 January 1	105 11 3	
	Received in 1956 under Deed of Covenant £57 10 0		
	Income Tax not yet refunded .. 42 10 0		
		100 0 0	
		205 11 3	
	Less Payments on Palomar Sky Atlas	298 19 10	
			93 8 7
£49,399			£47,912 19 3

Note.—Contributions unpaid at 1956 *December* 31, *amounting to* £220 10*s.* 0*d.*, *have not been included in these accounts.*

relating thereto, and certify them to be correctly drawn up therefrom, and in accordance with the Banks. We have not examined the records relating to contributions and admission fees of fellows,

W. B. KEEN & CO.,
Chartered Accountants.

General Fund Investments on 1956 *December* 31

Nominal		Book Value £	s.	d.	£	s.	d.
	British Government Stocks :						
£4,542 15 7	British Electricity 4½ per cent Guaranteed Stock, 1974/79	4,752	8	2			
£805 8 3	Exchequer 5 per cent Stock, 1957	805	1	3			
£6,073 9 0	Treasury 3 per cent Stock	4,460	15	10			
	(Market Value £8,517)				10,018	5	3
	United Kingdom Industrial Investments :						
600	Apex (Trinidad) Oil-Fields Ltd. Ord. 5*s*. Shares	1,216	18	6			
1,800	British Motor Corpn. 5*s*. Ord. Shares	888	6	6			
500	British Tabulating Machine Co. Ltd. Ord. £1 Shares	1,131	7	0			
2,000	City of London Brewery & Investment Trust Ltd. Def. 5*s*. Stock Units	1,632	10	6			
500	Courtaulds £1 Stock Units	924	11	6			
700	Dunlop Rubber Co. Ord. 10*s*. Stock Units	993	15	3			
600	Hawker Siddeley Group Ltd. Ord. £1 Shares	1,205	13	6			
40	Hudson's Bay Co. £1 Ord. Shares	394	4	6			
25	National Canning Co. Ltd. Ord. £1 Shares (Bonus Shares)		*nil*				
600	P. & O. Steam Navigation Co. Deferred Ord. £1 Stock Units	971	9	0			
400	Porritts and Spencer Ltd. Ord. £1 Stock Units	1,010	4	0			
150	Shell Transport & Trading Co. Ltd. New Ord. £1 Shares	1,320	6	0			
600	South African Distilleries and Wines Ltd. £1 Ord. Stock Units	914	0	3			
750	United Molasses Co. Ltd. 10*s*. Stock Units	1,332	13	6			
	(Market Value £12,789)				13,936	0	0
	Canadian Industrial Investments:						
50	Canadian Bank of Commerce Capital Stock $10 P.V. Shares	1,068	17	5			
200	Dominion Equity Investments Ltd. Common $1 Shares	1,182	7	3			
60	Dominion Stores Ltd. N.P.V. Shares	1,017	6	0			
50	Imperial Oil Ltd. N.P.V. Shares	1,080	6	6			
	(Market Value £4,077)				4,348	17	2
	U.S.A. Industrial Investments :						
60	Burroughs Corpn. Common $5 P.V. Shares	1,014	9	8			
50	International Utilities Corpn. Common $5 P.V. Shares	1,044	3	5			
40	Texas Co. Common $25 P.V. Shares	1,016	18	0			
45	U.S. Steel Corpn. Common $16⅔ P.V. Shares	1,050	5	11			
	(Market Value £4,154)				4,125	17	0
	(Total Market Value £29,537)				£32,428	19	5

Trust Fund Investments on 1956 *December* 31

Nominal £	s.	d.		Cost £	s.	d.
965	0	0	Agricultural Mortgage Corpn. 4½ per cent Deb. Stock, 1961/91	965	0	0
457	4	5	British Electricity 4¼ per cent Guaranteed Stock, 1974/79	404	12	10
1,004	0	0	Consolidated 4 per cent Stock	1,008	0	0
100	0	0	4 per cent Defence Bonds	100	0	0
1,846	4	0	Savings 3 per cent Bonds, 1955/65	1,876	4	5
1,765	17	8	" " " 1960/70	1,765	17	8
1,902	6	3	War 3½ per cent Loan	1,833	0	1
			(Market Value £6,397)	£7,952	15	0

GIFTS AND BEQUESTS TO THE SOCIETY

Full details of the circumstances and amounts of the gifts and bequests listed below are published quinquennially, together with revenue statements concerning the Special Funds and Trust Funds. The latest statement appeared in *M.N.*, **113**, 287, 1953.

GIFTS TO THE GENERAL FUNDS AND PROPERTY OF THE SOCIETY

The John Lee Gift (1836 and 1844)
The Lawson Bequest (1856)
The Carrington Bequest (1876)
The Lambert Bequest (1877)
The McClean Bequest (1905)
The Farrar Bequest (1906)
The Parsons Gift (1922)
The Grove-Hills Bequest (1922)
The Grove-Hills Fund (1922)
The Lindemann Bequest (1931)
The Archdeacon Potter Bequest (1933 and 1951)
The Goodridge Bequest (1936)
The Herbert Spencer Bequest (1936)
The Lindley Bequest (1937)
The Stanley Williams Bequest (1939)
The E. W. Brown Bequest (1939)
The Plummer Bequest (1946)
The Carder-Davies Bequest (1948)
The M. A. Nadarov Bequest (1950)
The W. H. Owston Bequest (1951)
The Rev. Harold Pain Bequest (1953)

SPECIAL FUNDS

The Archdeacon Potter Fund (1933 and 1951)
The Victor Nadarov Fund (1950)
The Arthur Stanley Eddington Commemoration Fund (1948)
Benevolent Fund (1950)
Palomar Sky Atlas Fund (1954)

TRUST FUNDS

The Lee and Janson Fund (1834 and 1879)
The Turnor Fund and the Horrocks Memorial Fund (1853 and 1876)
The Hannah Jackson (*née* Gwilt) Fund (1861)
The Harry Watson Memorial Fund (1923)
The George Darwin Lectureship Fund (1926)
The A. G. Stillhamer Trust (1937)
The E. W. Brown Trust (1939)
The Plummer Bequest (1946 and 1956)

SECOND INSTALMENT OF THE H. C. PLUMMER BEQUEST RECEIVED DURING 1956

Second distribution from residue of estate of Henry Crozier Plummer (*M.N.*, **113**, 292, 1953) ... ... £404 12*s*. 10*d*.

GIFTS TO THE GENERAL FUNDS AND PROPERTY OF THE SOCIETY DURING 1956

Mr Jack Miller ... ... £100 0*s*. 0*d*.

PROGRESS AND PRESENT STATE OF THE SOCIETY

	Patron	Institutional Members	Fellows: Compounded	Fellows: Annual Contributors	Junior Members	Associates	Total
1956 January 1	1	7	196	909	30	51	1194
Since elected		...	...	62	9	3	74
Fellows re-elected		...	...	1	...	...	1
Junior Members elected to Fellowship ..		...	...	3	− 3		0
Deceased 1956		...	− 7	− 9	...	− 2	− 18
Deceased before 1956, notified 1956 ..		...	− 1	− 1	...	...	− 2
Since compounded		...	1	− 1	...	...	0
Resigned 1956		...	...	− 33	...	...	− 33
Removed		− 1	...	− 5	...	− 1	− 7
1957 January 1	1	6	189	926	36	51	1209

(N.B.—Thirteen Associates are also Fellows, and are therefore counted twice in the above table.)

LIST OF PUBLIC INSTITUTIONS AND OF PERSONS WHO HAVE PRESENTED GIFTS (OTHER THAN BY EXCHANGE) TO THE LIBRARY DURING THE YEAR 1956

Academy of Sciences, Czechoslovakia
Academy of Sciences, U.S.S.R.
American Air Force, Cambridge Research Centre
Asociación de Aficionados a la Astronomía, Monte Video
Association for Applied Solar Energy, Phoenix, Arizona
Astronomical Department of the University of Thessaloniki
Astronomical Society of South Africa
Astronomical Society of Tasmania
Astronomische Gesellschaft
Astronomisch-Meteorologische Anstalt der Universität, Basel
British Astronomical Association
British Astronomical Association, New South Wales Branch
British Council
Carnegie Institution of Washington
Chapman and Hall
Comité d'Organisation du centenaire de la naissance de Henri Pioncaré
Commissione Geodetica Italiana
Crabtree & Co.
Defence Research Board, Canada
Faber and Faber
Goethe Link Observatory of Indiana University
Griffith Observatory
Government of India
H. M. Nautical Almanac Office
Imperial Chemical Industries
Institut d'Astrophysique, Liége
Institute of Navigation
International Astronomical Union
International Scientific Radio Union
Kommission Observatorium Wendelstein
Lund Observatory
Maria Mitchell Association
Thomas Nelson and Sons
National Oceanographic Council
National Research Council of Canada
Perkin-Elmer Corporation
Polska Akademia Nauk
Presses Universitaires de France
The Editors of Rise Hvézd
Royal College of Physicians
Royal College of Science
Royal Geographical Society
Royal Navy Benevolent Fund
Science Council of Japan
The Director, Science Museum
The Editors of Scientific American

Seismological Committee of the British Association
Sociedad Astronómica de México
Sterrenkundig Institut der Universiteit de Gent
Universitätssternwarte, Munster
University of California
Universytet Marii Curii Sklodowskiej i Lublin
The Editors of Urania
The Editors of Vega

Mrs W. M. Archibald
Mr E. A. Beet
Mr F. Benario
Sir David Brunt
Professor W. E. Curtis
Mr C. V. Deane
Dr A. Vibart Douglas
Mr C. C. L. Gregory
Professor O. Heckmann
Lady Jeffreys
Sir Harold Jeffreys
Sir Harold Spencer Jones
Professor M. Kamienski
Professor F. C. Leonard
Mr H. A. Lloyd
Mr N. E. Malin
Mr E. L. Martin
Sir Eric Millar
Mr C. T. Moss
Dr C. P. Olivier
Mr S. R. Pierce
Mr M. Schmidt
Mr B. Stavis
Mr Lyn Thorndike
Mr E. Tillotson
Dr G. de Vaucouleurs
Mr A. de Visscher
Dr G. J. Whitrow
Dr R. v. d. R. Woolley

OBITUARY NOTICES

WALTER SYDNEY ADAMS was born near Antioch in northern Syria in 1876 of parents who were American missionaries. He was brought to the United States when 8 years old. His astronomical training was excellent for he studied under several of the ablest astronomers in the world: Frost at Dartmouth College; Moulton, Laves, and Bolza at the University of Chicago; Schwarzschild and Seeliger at Munich, Germany.

He spent the years 1901–1904 at Yerkes Observatory working largely on stellar radial velocities. In 1904 Dr George E. Hale invited him to California as a charter member of the staff of the Mt Wilson Observatory which had just been established by the Carnegie Institution of Washington. For a few years Adams collaborated with Hale on solar observations but after the 60-inch telescope was completed in 1909 he assumed charge of the stellar department of the observatory and virtually all his future research was in stellar spectroscopy. For many years he shared with Hale responsibility for administering the growing observatory. During this period the 100-inch telescope was built and stellar research greatly expanded. After Hale retired in 1923, Adams became Director and served until 1946. He was an important member of various committes of the California Institute of Technology which had charge of planning and erecting the 200-inch telescope on Palomar Mountain. During World War II he was Vice-President of the International Astronomical Union, and, for a considerable period, performed the duties of the Secretary. For outstanding contributions to astronomy he received many high honours, including the Gold Medal of the Royal Astronomical Society in 1917. He died at his home in Pasadena on 1956 May 11.

Adams pioneered in the application of photography to the problem of solar rotation. His numerous measurements made from 1906 to 1908 of spectrograms taken at various solar latitudes with the powerful instruments on Mt Wilson set a new standard of accuracy and remain of great value. He took part with Hale in an extensive comparison of spectra of sunspots with spectra of the normal solar disk. The behaviour of the lines was also carefully compared with laboratory data. Enormous numbers of separate items were dealt with; one paper summarized results from the measurement and tabulation of 11 000 spectrum lines. This work was invaluable in establishing the conclusion that spots are characterized not only by temperature lower than that of the surrounding solar surface but also by the presence of fairly strong magnetic fields.

After about five years of solar work, Adams returned to the study of stellar spectra which he pursued for the remainder of his life. Here his newly acquired knowledge of solar phenomena proved to be a valuable asset. His main contributions are well known to astronomers. His longest programmes were on the following subjects: stellar motions, stellar luminosities and distances; properties of gases in interstellar space.

In the radial-velocity programmes carried out by Adams and his co-workers at Yerkes and Mt Wilson, the number of stars measured was about 8000, approximately half the total number measured by all observers.

In 1914 Adams, in collaboration with a visiting astronomer, Dr Arnold Kohlschütter, found that the absolute magnitude of many stars can be determined

from the relative intensities of certain lines in their photographed spectra. Adams' development of this useful fact made possible for the first time extensive measurements of stellar distances far beyond the reach of trigonometric parallaxes. This spectroscopic method, applied at Mt Wilson and elsewhere to many thousands of stars, has proved of immense importance in extending our knowledge of giant and dwarf stars and of galactic structure.

Adams' last extensive programme was the detailed study with high dispersion of interstellar lines in stellar spectra. Virtually all the hundreds of spectrograms required for this programme were taken and measured by Adams himself. The results established important facts concerning the nature and behaviour of interstellar gases.

From these large programmes Adams occasionally turned aside, but never for long, to make valuable studies of individual stars such as novae, α Orionis, o Ceti, companion to Sirius, and many others.

As an observer, Adams was skilful and indefatigable. If he thought a programme valuable, he was not deterred by the fact that it was long and arduous. Even when Director he spent nearly as much time at the telescope as any other member of the staff. His concentration on the task in hand and his skill resulted in the accumulation of great quantities of valuable data and in substantial progress in man's march toward fuller comprehension of the starry universe. The advantages of the powerful instruments he used were multiplied, so to speak, by sustained personal endeavour.

His fine personal qualities, such as great loyalty to Dr Hale, complete lack of affectation, and a quiet sense of humour, are partially revealed in his delightful reminiscences, "Early Days at Mount Wilson".* Dealings with his associates were characterized by courteous consideration and by many acts of pure kindness.

He was elected a Fellow of the Society in 1905, and an Associate in 1914.

PAUL W. MERRILL.

THADDEUS BANACHIEWICZ, younger son of Arthur Banachiewicz, landowner in the district of Warsaw, was born on 1882 February 13 at Warsaw. His interest in numbers began to reveal itself at a very tender age, but it was only during his stay at the Fifth Warsaw Gymnasium that he gave evidence of his remarkable mathematical abilities. At that time he became interested in astronomy, which gradually became his life-passion. He took his candidate-degree in Astronomy at the Warsaw University in 1904 and completed his studies in Göttingen under Schwarzschild and later in Poulkovo. He acted as junior assistant at the Warsaw Observatory during 1908–1909. In 1910 he obtained the degree of Magister Astronomiae at the Moscow University, after which he was appointed assistant at the Engelhardt Observatory, near Kazan, where he remained until 1915. The next three years, 1915–1918, he spent in Dorpat where he was successively Assistant, Docent and Professor Extraordinarius. In 1918 he returned to his native country. Here, after a short stay in Warsaw as Docent of Geodesy at the Warsaw High Polytechnic School, he went to Cracow to fill the chair of astronomy offered him by the Jagellonian University. At the same time he was appointed Director of the Cracow Observatory where he resided until his death. The Cracow period of his life, extending over 35 years (1919–1954), was a long period of most fruitful activity. An interruption occurred

* *P.A.S.P.*, **59**, 213, 285, 1947.

only in the winter months of 1939–1940 when the Cracow professors were taken to the Gestapo concentration camp at Sachsenhausen, near Berlin. Here Banachiewicz had to endure physical and moral deprivations which he met with dignity and disdain. And here Banachiewicz remained faithful to his device—life is work—and notwithstanding the miseries of cold and hunger, having no books and hardly a piece of paper and a pencil at his disposal, he continued to work on his theory of cracovians.

The range of his scientific interests was very wide and his contributions to astronomy, mathematics, mechanics, geodesy and geophysics are of outstanding merit. His great power of intuition helped him to find the right way towards the solution of problems and his mathematical analysis was deep and thorough. His papers are written in a clear style although they often refer to most difficult and subtle questions.

The general trend of his life-work was theoretical. He published several papers on Gauss' equation, $\sin(z-q)=m\sin^4 z$ and gave very useful tables facilitating the numerical solution of this equation. These tables have been reprinted in Bauschinger-Stracke's " Tafeln zur theoretischen Astronomie ".

Banachiewicz paid much attention to the question of multiple solutions in the problem of determination of parabolic orbits and gave the most concise and clear account to be found anywhere of this important matter. He modified and simplified Olbers' method of determining parabolic orbits, and also simplified the determination of elliptic orbits.

Banachiewicz applied with success his theory of cracovians to the problem of correction of orbits. Both his methods—the direct and the quaternion one—lead to a simple, elegant and practical solution of the problem. Convenient cracovian formulae were introduced by Banachiewicz for computing the precessional effect on star-coordinates; his orthogonal transformation formulae facilitate the reduction of the vectorial elements of planets and comets from one epoch to another. Tables of numerical values for this method are published in *Cracow Ephemerides* and in *Planetary Coordinates*.

These new methods of determining, as well as correcting, orbits, adjusted to a new technique of computing, presented a noticeable improvement in this domain since the days of Olbers and Gauss. Such progress could be achieved only with the help of a new mathematical method and new computing schemes. It was for this purpose that Banachiewicz invented the Cracovian Calculus. The cracovians are related to Cayley's matrices but differ theoretically in the definition of the product, the multiplication of cracovians being that of column by column. This change in the product rule makes cracovians more suitable for machine computation. In the hands of his school the cracovians became a useful and powerful mathematical tool, well adapted to theoretical research and practical applications. Among the problems treated by cracovians, the following may be quoted as being of outstanding importance: the method of least squares, spherical polygonometry, theory of interpolation, linear equations, cracovian nuclear algebra, power series in two or more variables. The invention of rotary cracovians enabled Banachiewicz to obtain the solution of the general problem of spherical polygonometry searched for in vain by mathematicians for over a century.

Banachiewicz was not only a prominent theorist but also a gifted and assiduous observer. While a university student he began to observe occultations of stars

by the Moon, having in view their importance for the study of the motions of our satellite; in this respect he was 20 years ahead of Brown. He developed a purely numerical method for the prediction of occultations of stars which saves much time in comparison with the graphical methods used heretofore. He was also interested in occultations of stars by planets. It was thanks to his ephemerides that due attention was paid to the occultation of 6G Librae by Ganymede, Jupiter's III satellite, on 1911 August 13, which was observed in Chile, Australia and China; important consequences could be drawn from these observations in respect of the diameters and positions of Jupiter and the III satellite. During his stay in Kazan he carried out observations on the Moon's libration with a four-inch heliometer. This series, extending over four years, was the third Kazan series; it was reduced and published by Jakovkin and proved to be of great precision. Later on Banachiewicz attacked the problem of the Moon's libration, making use of his cracovian calculus, modifying Bessel's classic method and introducing several innovations.

Banachiewicz attached much importance to observations of eclipsing variables and introduced them into the working programme of the Cracow Observatory. Notwithstanding his multiple occupations he personally took part in those observations. He saw in eclipsing binaries the clue to many important questions of the sidereal universe and insisted on gathering observational material for " the future Kepler of eclipsing binaries ". He thought to use eclipsing binaries of short period for the determination of " cosmic time " independent of irregularities of the Earth's rotation.

Being interested in questions of higher geodesy, he took part in gravimetric observations during his Kazan period. Later on, as director of the Cracow Observatory, he organized in Poland gravimetric observations and first-order levelling. He was a permanent representative of Poland in the Baltic Geodetic Commission. At the Berlin meeting of this Commission (1928 September), Banachiewicz communicated the results obtained by the Polish solar expedition (1927 June 12) in timing a solar eclipse by his " chrono-cinematographic " method. This method makes use of Baily's beads and thus greatly increases the number of observed contacts between the two heavenly bodies. The difference in right ascension (Moon–Sun) could be established with a mean error of $\pm 0''\cdot 04$. The new method offers thus great advantages over the older geometrical methods. Banachiewicz proposed therefore to use total eclipses for the purpose of connecting distant points of the Earth's surface : lunar triangulation can thus be successfully applied to cases where ordinary triangulation is ineffective—the bridging of oceans. The contact times obtained by the chrono-cinematographic method can give the distance between two observing stations with an error of ± 35 m. Having in view his geodetic application, Banachiewicz organized three Polish expeditions to observe the 1936 June 19 eclipse, with sites in Greece, Siberia and Japan. On account of cloudy weather in Japan and partly in Siberia the results were poor. Banachiewicz's ideas were taken up and developed by Bonsdorff, Lindblad and others and many attempts have since been made to apply lunar triangulation.

In the domain of astrophysics Banachiewicz gave preference to photometric problems. Besides the photometry of variable stars he was occupied for some time with the question of illumination of planetary disks and with the illumination of our sky.

In the last years of his life he was greatly impressed by the successes of radio-astronomy. Thanks to his initiative the first Polish radio-telescope of 5 m diameter, 2 m focal distance and wave-length 90 cm was set up at Fort Skala, near Cracow, a branch station of the Cracow Observatory. The solar eclipse of 1954 June 30 was observed with this instrument.

Throughout his life, Banachiewicz was a zealous and skilful computer. He could spend 24 hours at a stretch with his Brunsviga to obtain the answer to a problem which occupied his mind. He had much accumulated experience and a wonderful gift of detecting errors by mere inspection.

Banachiewicz was fond of teaching. His lectures displayed a power of very lucid exposition, an excellent command of language and a high scientific level; they were much frequented by students and graduates. Banachiewicz had many pupils—some of them occupy at present responsible posts in Polish universities.

Polish astronomy is indebted to Banachiewicz for his activity in organization. At the time he took charge of the Cracow Observatory it was in a poor state. He set up a new working programme adapted to the very modest instrumental equipment of the observatory and concentrated his efforts on the completion of the staff. Because of the poor observing conditions at the old observatory, situated in the midst of a large city, he set up a branch station on Mount Lubomir (912 m), 30 km to the south of Cracow, which was burnt down by a Gestapo detachment in 1944. Shortly before his death Banachiewicz began the building of a new branch station at Fort Skala, in the vicinity of Cracow.

Banachiewicz published 240 scientific papers and wrote several text-books: *Methods of Astronomical Computation*, *Determination of Orbits* (in print), *Cracovian Calculus and its Applications* (in print). Hundreds of popular articles, newspaper notices, communications, popular lectures, a great scientific correspondence of some 15 000 letters in Polish, Russian, English, French, German and Interlingua are a testimony to laboriously spent years.

Banachiewicz received many distinctions. He was elected member of the Cracow Academy of Sciences in 1922, as well as member of the Warsaw Scientific Society. The Universities of Warsaw (1928), Poznan (1938) and Sofia (1950) conferred upon him the title of honorary doctor. He was Vice-President of the Baltic Geodetic Commission in 1924–1925, Vice-President and member of the Executive Committee of the IAU in 1932–1938, President of Commission 17 of the IAU (Movements and Figure of the Moon) from 1938. He was a member of the Polish Academy of Sciences, a member of the Padova Academy and an Associate of our Society. He was one of the founders of the Polish Astronomical Society and for many years its President. He received many distinctions, Polish as well as foreign ones. The 50th year of his scientific activity was celebrated by the Polish Academy of Sciences on 1954 March 15 at a solemn session. The Council of the State awarded him on that occasion the Order of Labour of the first class.

He was widely known and highly respected in scientific circles abroad. In acknowledgment of his scientific merits Professor S. Arend gave the name of Banachiewicza to a minor planet.

Banachiewicz was married to Laura Sollohub who died in 1945; they had no children.

Up to the last days of his life Banachiewicz was active as a scientist. In 1954 May he went to Leningrad to assist the inauguration of the Poulkovo

Observatory. He arrived in Leningrad in a bad state of health and was compelled to stay there a month in hospital. In July he returned to Cracow where he underwent an operation. However, his health did not improve and he died on 1954 November 17 of pneumonia.

In Poland and abroad many mourn the passing away of a friend; many others who admired his scientific achievements are no doubt conscious of this great loss to science. He is no more, but his work will endure. To him may be applied Kepler's words:

Non frustra vixisse videtur.

J. WITKOWSKI.

GRIGORI ABRAMOVICH SHAJN, eminent Soviet astrophysicist, died after a short but severe illness in his sixty-fourth year.

He began his career as a scientist in the State University of Perm, later working in Tomsk University, at the Poulkovo Observatory and, since 1924, at the Simeis Observatory. In 1939 he was elected an Academician. After the War he was in charge of the restoration and further work of the Simeis Observatory, and he was responsible, too, for the building up of the Astrophysical Laboratory in the Central Crimea—the largest of its kind in the U.S.S.R.—of which he was Director from 1944 to 1952.

Soviet science is indebted to G. A. Shajn for the broad development of modern astrophysics in that country, in particular the development of the study of the physics of stars and of interstellar space. In these fields he carried out valuable research and created new trends of thought. Among his works one should note the discovery of the rotation of stars, and of the anomalous carbon and nitrogen isotope content in stars which was of great importance in solving problems of stellar evolution and of nuclear physics. His discovery of new gaseous nebulae and their systematic study provided a new page in the physics of the interstellar medium, and made possible a deeper understanding of the part played by these formations in the evolution of stellar systems.

The whole of Shajn's activities were distinguished by devotion to science, by appreciation of new ideas, by the ability to reach deep down to the essential physical nature of phenomena, and by his absolute firmness of principles. His services to science were well recognized by his Government and by public opinion in the world of science; he was twice honoured by awards of the Order of Lenin, and was elected to membership of many Soviet and foreign scientific societies; he was elected an Associate of the Royal Astronomical Society in 1937.

His untimely end in 1956 came upon Shajn when he was still at the height of his creative powers and activities.

Soviet scientists, and all who knew him personally, will remember him as a notable scientist and as a fine man.

From *Izvestia*, 1956 *August* 8.

HENRY FREDERICK BAKER, Fellow 1914–1936, was born on 1866 July 3, and was educated at the Perse School and St John's College, Cambridge. He was bracketed Senior Wrangler with three others in 1887 and was a Smith's Prizeman two years later. He became Fellow, Lecturer and Director of Studies in Mathematics in St John's College.

He worked in most fields of pure mathematics. His principal courses of undergraduate lectures were on Theory of Functions, Geometry, Differential Equations, and Analysis (which meant what is now usually called Special Functions); but he was quite capable of giving one on dynamics or elementary electricity in an emergency. His speed was amazing. A contemporary of mine took notes in shorthand and made a fair copy afterwards, which was in great demand. But if anybody confessed to being bewildered, Baker would explain every detail at extreme length.

He had written books on *Abelian Functions* (1897) and *Multiply-periodic Functions* (1907); ideas from these generalizations of elliptic functions permeated much of his work on geometry, and later, on figures of rotating fluids. He is best known for his book *Principles of Geometry* (6 vols, 1922–33). The first four volumes deal with projective geometry of two, three, and four dimensions. In these he makes much use of synthetic (or, as we should now say, axiomatic) methods, without the use of co-ordinates. To those trained in the tradition of C. Smith and Askwith it was astonishing that so much could be done in this way. In the last years of his tenure of the chair his lectures were mainly on the birational theory of curves and surfaces, and the last two volumes of the *Principles* deal with this subject. The modern tendency is closer to his later methods than his earlier ones; co-ordinates are introduced as early as possible, and the distinction between geometry and algebra has almost disappeared.

He became a Fellow of the Royal Society in 1898 and received the Sylvester Medal in 1910. For a time he was Senior Fellow of the Royal Society.

He was elected to the Lowndean Professorship of Astronomy and Geometry on 1914 January 5 in succession to Sir Robert Ball. The appointment surprised most people not actively concerned in it, and it is believed that the electors were equally divided and that the decision was made by the Chancellor, Lord Rayleigh. The chair had been held by astronomers throughout the nineteenth century, and Baker had written no specifically astronomical work. A consideration that probably influenced the electors was that there was only one chair in the whole of pure mathematics, while astronomy had three. Another was that geometry was mentioned in the title of the chair; but to this astronomers had the reply that geometry had often been used in a very wide sense. Laplace, Leverrier and Adams had been referred to as geometers. In any case Baker's own diffidence would have prevented him from being a candidate unless he had been encouraged to enter by some of the electors.

Having been elected, Baker proceeded to make himself a Professor of *both* astronomy and geometry. A fortnight from his election he began a course of lectures on Periodic Orbits, in addition to three regular College courses. In this he showed familiarity with all treatments of the subject, which must have been among his interests for some time. In a paper in the Philosophical Transactions for 1916 he studied certain differential equations with periodic and what would now be called almost-periodic coefficients, introducing some new methods of solution, and proved the existence of convergent solutions. In one respect he amended a result of Poincaré. He returned to the subject in the Proceedings of the Cambridge Philosophical Society for 1920. He also lectured on planetary, lunar and satellite theory, and on figures of rotating liquids. A paper on the derivation of the equations of motion is in *Monthly Notices*, **87**, 93, 1927. He was for some time sceptical about Jeans's proof of the instability of the pear-shaped

figure, doubting the accuracy of the first few terms as an approximation to the sum of a certain series; but he managed to obtain a copy of Liapounoff's works and found that Liapounoff had actually got a result that amounted to a justification of Jeans's method. Baker was the first Englishman to understand Liapounoff.

Besides his own work he gave valuable help to younger workers, notably Greaves.

He published many papers on a range of subjects comparable with that of Poincaré. One, in the Cambridge Proceedings for 1920, discusses the Lorentz transformation of the electromagnetic equations, and incidentally includes the Pauli and Eddington matrices.

His contribution to pure mathematics with the widest application was possibly to notice that the bisection method used by Goursat in his proof of Cauchy's theorem could be adapted to give general proofs of the Heine–Borel theorem and the so-called modified Heine–Borel theorem.

He retired in 1936 and died on 1956 March 17. He was active mentally till the last.

HAROLD JEFFREYS.

CLARENCE AUGUSTUS CHANT died on 1956 November 18 at his home, Observatory House at the David Dunlap Observatory near Toronto, at the age of 91. Often referred to as the Dean of Canadian Astronomy, he had devoted his long life almost entirely to the advancement of astronomy in Canada through his services to the University of Toronto and to the Royal Astronomical Society of Canada.

Chant was born near Toronto on 1865 May 31. After finishing his early education he taught school for a year before entering the University of Toronto. He graduated in honours mathematics and physics in 1890, and the following year he accepted a teaching post in physics at the University.

At this time Hertzian waves and Roentgen rays were novel, and Chant is credited with sending the first wireless massage in Canada and with making the first use in Toronto of X-rays for medical purposes. It was for research in Hertzian waves that he received a Ph.D. from Harvard University in 1901. Although his greatest contributions were to astronomy, his interests in physics never waned; in fact physics text-books of which he was co-author are still in use in Ontario schools.

In 1892 Chant became interested in astronomy through membership in the Astronomical and Physical Society of Toronto which had just been incorporated and which became, the following year, the Royal Astronomical Society of Canada. He was president of this society from 1904 to 1907 and it was thanks to his leadership that the society, originally confined to Toronto, broadened out to embrace centres across Canada and launched its *Journal* and *Observer's Handbook*. He was editor of both these publications from their inception in 1907 until the time of his death—exactly fifty years.

At the same time that he was unifying Canadian astronomy, both amateur and professional, through his work in the Royal Astronomical Society of Canada, Chant was setting out to improve the position of astronomy at the University of Toronto. In 1904 at his urging there was established a sub-department of astrophysics which later grew under his direction into the Department of

Astronomy and which offered a graduating course and post-graduate work in astronomy.

Lacking for so many years a telescope of any size at Toronto, Chant confined his astronomical research mainly to the observation of solar eclipses. He led five eclipse expeditions, the most important of which was the one to Australia in 1922 when he and R. K. Young, later his colleague and successor at Toronto, obtained one of the first verifications of the Einstein prediction regarding the deflection of sunlight by the Sun's gravitational field.

The lack of an observatory at Toronto irked Chant and drove him to tireless efforts to obtain one. After many disappointments, finally in 1928 his efforts began to bear fruit when Mrs Jessie Donalda Dunlap, impressed by his enthusiasm, offered to build and present to the University an observatory in memory of her late husband who had earlier shown interest in the project. After seven years of planning, Chant saw the David Dunlap Observatory opened on his seventieth birthday, 1935 May 31. On this same day, he was awarded an honorary LL.D. from the University of Toronto and retired to become Professor Emeritus of Astronomy and Director Emeritus of the Observatory.

After his retirement he was far from idle. He lived on the Observatory property, had an office at the Observatory and kept very busy with his writing, the revision of his books and the editing of publications. Until a few years ago he was in vigorous health, but infirmity kept him confined to his house during the last two years. Nevertheless he maintained alert interest in all things relating to astronomy up until the day of his death, and his courtly manner and scholarly speech never deserted him.

Chant was well known to the older British and European astronomers. As a young man he had studied physics for a while at Leipzig; in the 1920's and 1930's he attended several meetings of the International Astronomical Union; and while the David Dunlap Observatory was being built he paid several visits to the works of Sir Howard Grubb, Parsons and Co. Ltd., where the 74-inch telescope was built. His excellent popular treatise *Our Wonderful Universe* was printed in two editions in England and in five foreign language editions.

Mrs Chant predeceased him in 1943 and he is survived by two daughters, Mrs R. W. Hopper and Dr Elizabeth Chant Robertson of Toronto.

He was elected a fellow of the Society on 1924 March 14.

J. F. HEARD.

RALPH EMERSON DELURY was born in Manilla, Ontario, the eighth child of David DeLury and Catherine Weir, in 1881. He received his early education at the public school in Manilla and at the Port Perry High School. He later attended the University of Toronto and received in turn a Bachelor's, Master's and Doctor's degree in 1903, 1904 and 1907 respectively. Mathematics, physics and chemistry were his special subjects. From 1903 until 1906 he held a Fellowship at his alma mater and the following year he was an assistant in the Department of Physical Chemistry at Princeton University.

DeLury joined the staff of the Dominion Observatory, Ottawa, Canada, in 1907. While his scientific interests were varied, the problems dealing with solar rotation and the correlations between sunspots and various terrestrial phenomena constituted his special investigations and he published many papers concerning these research problems. He became head of the Solar Physics Division in

1913, Assistant Director in 1929 and acting Dominion Astronomer for a short time before his retirement in 1946.

Ralph DeLury was a very modest man and shunned any pomp or affectation. Although well-known in scientific organizations, he also made many friends through his active interest in things pertaining to nature and wild life. To those who knew him even slightly it was evident that he was a true lover of nature. His gentle and patient care of the birds and little animals which frequented his home was an outstanding and lovable characteristic. Children in his neighbourhood soon recognized him as their friend and to many he taught that the rewards were far greater if a camera, not a rifle, were used in "shooting" birds.

As evidence of this great interest, his Ottawa home became a veritable bird sanctuary and many injured birds received care, food and shelter until again able to face the world on their own. They too became his intimate friends. Following retirement, Dr DeLury returned to the home of his birth to enjoy his hobby at leisure. His Manilla estate in turn became a sanctuary for birds and waterfowl, and it was in such surroundings that he enjoyed his years of retirement.

As a younger man Ralph DeLury was a keen sportsman, with baseball and tennis his main activities in this field. His interest in baseball never lessened with advancing years, and radio and television added much to his enjoyment in following this sport.

The list of organizations of which Dr DeLury was a Fellow or a member includes the following: Fellow of the Royal Astronomical Society of Canada; Fellow of the Royal Society of Canada; Fellow of the London Chemical Society; American Association for the Advancement of Science; Optical Society of America; Deutsche Astronomische Gesellschaft; American Astronomical Society; American Statistical Society; Société Astronomique de France; American Society of Mammalogists; Ornithological Union; Cooper Ornithological Club; Wilson Ornithological Club. He was elected a Fellow of our Society on 1920 January 9.

Dr DeLury was married in Ottawa to Isobel MacBrien, who predeceased him in 1913; there were no children. The surviving members of his family are a sister Abigail of Manilla and two brothers, Daniel B. of Walker, Minn., and Justin S. of Uxbridge, Ont.

C. S. BEALS.

DONALD LUTHER EDWARDS, director of the Norman Lockyer Observatory of the University of Exeter for almost twenty years, died after a very short illness on 1956 September 23.

He was born in Peterborough on 1894 January 11; and was educated at the Cambridge County School, and the Royal College of Science, London. As a child, he showed great interest in astronomical topics.

He always intended to be an astronomer; and when in his 'teens he built himself a telescope to aid his lunar studies.

On demobilization from the Royal Engineers after the First World War, Edwards went to Sidmouth in 1919 May as assistant to Sir Norman Lockyer, first director and founder of the Hill Observatory (as it was then called), subsequently to spend the whole of his working life in the service of that institution. In 1921 he was appointed chief assistant; and, following the death of W. J. S. Lockyer in 1936, he became director.

During the years prior to 1936 Edwards's main interest was in the application to objective-prism spectra of a method for determining stellar parallaxes first suggested by W. S. Adams in 1921. Between 1922 and 1930, spectroscopic parallaxes of 200 B-type stars were published in a sequence of six papers appearing in *Monthly Notices*.

More recently he had continued the spectroscopic study of the irregular variable, γ Cassiopeiae, commenced by the younger Lockyer in 1923; and he had contributed an article on this star to the second volume of *Vistas in Astronomy* (1955). At the time of his death he was engaged on the preparation of a paper dealing with an early outburst of γ Cassiopeiae in 1882–8, based on an analysis of visual observations made by J. Plassmann at Münster.

During his tenure of the directorship, Edwards worked always to preserve the best of the Lockyer tradition, and to promote the original purpose of the Observatory, so fittingly expressed by its motto—*Sic itur ad Astra*. As Sir Richard Gregory remarked on the occasion of the transfer of the Observatory Corporation to the then University College of the South-West of England, in 1948 May, the notable output of original communications had been well maintained since 1936.

A careful and assiduous observer, he was painstaking and thorough in all that he undertook. He loved his work, and sought no reward other than that to be derived from the satisfaction of a task well done.

Edwards was elected a Fellow of the Society on 1921 May 13, and served on the Council from 1946 to 1950. He was also a member of the British Astronomical Association, which he joined in 1915.

He married in 1919 September Miss Elsie Stanley, of Wednesbury, who survives him. There are no children of the marriage.

D. R. BARBER.

JOHN EVERSHED was born on 1864 February 26, at Gomshall in Surrey of a family of yeoman farmers who could be traced from father to son living on the same farm for 500 years. He died on 1956 November 17, and with his death a link is broken with the active astronomers of the last century. Educated privately, he was at first employed by a firm of chemical manufacturers in analysing oils and other products. He had already begun, with apparatus largely home-made, a long series of observations on solar prominences; one of the directors of his company being interested in scientific work, he obtained leave of absence to join eclipse observations organized by the British Astronomical Association in 1896 and 1898 to Norway and India. In India with a home-made prismatic camera he got beautiful spectra extending far into the ultraviolet; he obtained the first evidence of the Balmer continuum and discovered a new coronal line at λ 3388. It was at the 1896 eclipse that he met Miss Mary Acworth whom he married later. Mrs Evershed collaborated closely with him for years in his solar work. Other eclipses that he observed were in Algeria, 1900; Spain, 1905; Australia, 1922; and Yorkshire, 1927.

Ranyard, who with Hale nominated Evershed for Fellowship of the Society, presented him with an 18-inch reflector and a small spectroheliograph which Evershed installed at Kenley; after modifying and greatly improving the latter instrument Evershed carried out successful monochromatic photography of the Sun.

In 1906, on the initiative of Gilbert Walker, then Director of Observatories in India, he was appointed assistant director of Kodaikanal Observatory under Michie Smith, whom he succeeded in 1911. He travelled out to India *via* the United States visiting a number of observatories and spending a month with Hale at Mt Wilson. In Kodaikanal he continued his work on prominences and with Mrs Evershed he published an important memoir on the distribution of prominences in latitude during the solar cycle. He greatly improved the quality of the instrumental equipment of the Observatory, designing and building a large spectrograph using a 5-inch grating by Michelson. His most striking discovery was that of radial motion in sunspots—accelerating motion outward in the reversing layer and inward in the higher chromosphere. It was for this work largely that he was elected to the Royal Society in 1915 and received the Gold Medal of the Royal Astronomical Society in 1918.

Other work carried out at Kodaikanal included spectrographic measures of solar rotation, photographs of Halley's comet showing the acceleration of matter in the tail and spectrograms showing the strong cyanogen bend at λ 3883 in the head; large scale spectra of Nova Aquilae 1918 were also obtained. With Royds he worked on the shifts to the red of iron lines in the solar spectrum at the centre of the disk and at the limb, examining the pressure in the reversing layer, and the relativity shift. His final conclusion was that the Einstein effect is present together with some additional cause affecting the wave-lengths at the limb. He spent seventeen months in Kashmir examining the seeing conditions and came to the conclusion, confirmed subsequently in New Zealand, that for solar definition high mountain sites or even hill-tops are less favourable than enclosed valleys and low-level plains.

On his retirement from Kodaikanal in 1923, with the award of a C.I.E. in recognition of his services, he established a private observatory at Ewhurst in Surrey and built a large spectroheliograph of special design and a spectrograph with a high-dispersion liquid prism. He continued to study the wave-lengths of H and K lines in prominences, giving values of the solar rotation at high levels in different latitudes and at different phases of the solar cycle. At Hale's request he measured a typical series of the Mt Wilson magnetic field spectra. He confirmed the displacements of the lines secured at Mt Wilson; failing, however, to get confirmation from a line that should have shown a greater magnetic effect, he decided that the displacements found at Mt Wilson were due to Doppler effect and that there was no evidence of a general magnetic field in these spectra.

Evershed continued at work until 1950 when he closed his observatory and presented some of his instruments to the Royal Greenwich Observatory at Herstmonceux. He married Miss Mary Acworth in 1906. She died in 1949. In 1950 he married Miss Margaret Randall, who survives him. There were no children. He was a founder member of the British Astronomical Association and director of the Sections of Solar Spectroscopy and later of Spectroscopy.

He was elected a Fellow of the Society in 1894.

F. J. M. STRATTON.

HECTOR COPLAND MACPHERSON was born in Edinburgh on 1888 April 1 and died there on 1956 May 19.

It was from his father, Mr Hector Macpherson—for many years editor of the *Edinburgh Evening News*—that he received much of his early education and derived his inspiration to write and lecture on astronomy. His first article was published when he was fourteen years old. It was entitled *Is Mars Inhabited*? and appeared in the weekly *North British Advertiser*. There followed in the same paper a long series of biographies under the title *Famous Astronomers*. Much research had to be done ; and the boy, Hector, having dealt with Huggins, Gill and others, wrote for information to Schiaparelli and was delighted to receive a detailed and courteous reply. Thus encouraged, he corresponded with thirty-two other continental and foreign astronomers; with some of whom he established lasting friendships. When the *North British Advertiser* articles were complete, and the author was still under seventeen, they were published in book form by Gall and Inglis under the title *Astronomers of To-day*.

He then had to think of a career ; and entering Edinburgh University he took his theological training at New College, where he collected many honours including the Cunningham Fellowship. In 1916 he was appointed minister of Loudon East Church, Newmilns, Ayrshire. He served for a period with the Y.M.C.A. in France in the First World War, and in 1921 took charge of the Guthrie Memorial Church, Edinburgh, where he preached for the next thirty-five years.

Macpherson soon established himself as a forceful preacher and became noted as a leader in Church youth and temperance work. His intellectual energies also expanded, and in 1922 he published an important history of the Covenanters movement—*The Covenanters under Persecution*—for which in the following year he was awarded the honorary degree of Ph.D. by Edinburgh University.

Notwithstanding the demands of his pastoral work, Dr Macpherson continued to write and lecture fluently on astronomy. In 1906 he had published the book *A Century's Progress in Astronomy*, which was followed by *Through the Depths of Space*, and by *The Romance of Modern Astronomy* (1911). In 1919 he had published a biography of Herschel in the *Pioneers of Progress* series and also *Practical Astronomy*. These were followed by *Modern Astronomy: its Rise and Progress* (1926)—which was perhaps his most successful work—*Modern Cosmologies* (1929), *Makers of Astronomy* (1933), the Church of Scotland booklet *The Heavens Declare* (1937) *Biographical Dictionary of Astronomers* (1940), *Guide to the Stars* (1943), and the revision of the latter (1953), which was the last published writing on his life-long hobby.

In the volumes of *The Observatory* for the years 1909–1940 will be found about a dozen of his articles—biographical studies of Herschel, Newcomb, Dunér and the Struve family, cosmological essays and reviews of work on nebulae. In this period he also contributed articles of similar scope to *Popular Astronomy*.

All his work was characterized by wide reading and careful historical research, and many of his books were based upon the lucid " popular " lectures which he delivered under the auspices of the Robert Cormack Committee of the Royal Society of Edinburgh and the David Elder foundation in Glasgow. He took a leading part in the foundation of the Edinburgh Astronomical Association (now the Astronomical Society of Edinburgh) and served as its President in the years 1926–1928 and 1952–1954.

In 1917 Dr Macpherson married Miss Catherine Anne Chisholm and there were two sons and two daughters of the marriage. To his elder son, Hector, I am indebted for many of the above details.

Dr Macpherson was elected F.R.S.E. in 1917 and a Fellow of our Society in 1911.

M. A. ELLISON.

EDMUND TAYLOR WHITTAKER was born at Southport, Lancashire, on 1873 October 24, and died in Edinburgh on 1956 March 24. The family to which he belonged, the Whittakers of Grindleton near Clitheroe on the Ribble, had produced men of distinction in public life during the latter part of the nineteenth century. After an education at the Manchester Grammar School, Whittaker went up to Trinity College, Cambridge, in 1891 with an entrance scholarship. He was Second Wrangler in the Tripos of 1895, was elected to a Fellowship at Trinity in 1896 and was First Smith's Prizeman in 1897. Elected to Fellowship of the Royal Society in 1905, at the early age of 31, he was appointed Royal Astronomer of Ireland and Professor of Astronomy in the University of Dublin the following year. He had become a Fellow of the Royal Astronomical Society in 1898 and served as Secretary from 1901 to 1907. In January 1912, Whittaker succeeded Chrystal as Professor of Mathematics at Edinburgh, a Chair he occupied until his retirement in 1946. He was knighted in 1945 and during his long and distinguished carreer had received a multitude of honorary fellowships, doctorates, memberships of foreign academies, the Sylvester and Copley medals of the Royal Society, the De Morgan medal of the London Mathematical Society and, in 1935, an honour that he greatly prized, the Cross *Pro Ecclesia et Pontifice* conferred on him by H.H. Pope Pius XI.

Whittaker revealed early his peculiar genius for presenting to his contemporaries complete accounts of branches of pure or of applied mathematics illuminated by a new point of view and infused with the results of his own researches. By the age of 30 he had discovered the general solution of Laplace's equation, had introduced the hypergeometric function and, in 1902, published his first book, *Modern Analysis*. In its later editions, written after 1915 in collaboration with G. N. Watson, this book became, and for long remained, the standard text on the complex variable. It also had the character of a small encyclopaedia on special functions and their differential equations. In 1904 came the *Analytical Dynamics* which revolutionized the teaching of advanced dynamics in Britain and, as successive editions were issued, came to contain his own researches, such as the theorem on the existence and position of periodic orbits and the theory of the adelphic integral of a Hamiltonian system. During his years in Edinburgh, Whittaker not only founded and developed what was probably the first school of numerical analysis in Britain, but also himself contributed to the theory of interpolation. These questions were brought to his attention through his friendship with the actuaries of the Life Assurance companies, many of which have their head offices in Edinburgh. He introduced the concept of the cardinal function of a set of cotabular functions and also wrote on the theory of graduation. Once again the whole subject was brought together in the *Calculus of Observations*, published in 1924 in collaboration with G. Robinson. And simultaneously with these larger works there came from his pen throughout his life a stream of research papers on a bewildering variety

of topics: automorphic functions, algebra, special functions, interpolation, the general theory of orbits, relativity, quantum theory and even two short observational papers on the variable stars RW Cassiopeiae and SS Cygni, published in *M.N.*, **71**, 511 and 686, 1910*.

His greatest work, the *History of the Theories of Aether and Electricity, from the age of Descartes to the close of the Nineteenth Century*, was originally published in Dublin in 1910, with a revised and amplified edition in 1951 that was followed in 1953 by a second volume bringing the history down to 1926. It reveals not only his exceptional understanding of the work of his predecessors and contemporaries, but, more significantly, his capacity for reacting to it in an original way. For example, his study of the literature led him to attribute the basic ideas of special relativity to Poincaré and Lorentz rather than to Einstein. That the *History* could be written at all was due to a rare quality of his mind: most men as they pass through their twenties gradually lose the ability possessed in youth of learning and digesting new material quickly. With Whittaker the opposite appears to have been the case; new knowledge on a wide variety of topics was rapidly assimilated and incorporated into the previously existing corpus. His students well remember the advanced lectures he gave each term to his staff and research students. In one term he would be lecturing on the latest developments in the theory of automorphic functions; in the next, there would be a brilliant account of a just-published unified field theory of gravitation and electromagnetism. He once said to the present writer: "The 1951 and 1953 volumes of the *History* could not have been written had I not, all my life, read widely and kept notes about what I had read." This was an unduly modest estimate; without passing through the crucible of his lively mind, such an encyclopaedic knowledge might have resulted in the dullest of catalogues. Instead there is an exposition, with some of the compulsive character of a detective story, which leads the reader on to the present-day solutions of the problems of gravitation, electromagnetism and the quantum theory of the atom.

Another aspect of Whittaker's character, perhaps uncommon in men who devote themselves to the cold abstractions of mathematics, was his lively interest in, and sympathetic understanding of, the human problems of those about him. While he was always ready with counsel to those who came to him for advice his innate courtesy forbad intrusion into what he regarded as the privacy of others. A deeply religious man, well versed in the theological and philosophical problems of religion, who had joined the Roman Catholic Church in 1930, he yet never thrust his religious views on those who might not share them. The generous impulse that always led him to give help where help was wanted is exemplified by his undertaking to edit and publish the posthumous manuscript of Eddington's *Fundamental Theory*. And here again he added his own elucidation and interpretation of this difficult book in *From Euclid to Eddington* (1949).

He is survived by Lady Whittaker, daughter of the Rev. Thomas Boyd, whom he married in 1901, and by their three sons and two daughters.

G. C. MCVITTIE.

* A complete bibliography will be found in *Biogr. Mem. Roy. Soc. Lond.*, **2**, 229–325, 1956.

PROCEEDINGS OF OBSERVATORIES

Royal Greenwich Observatory

(*Director, Dr R. v. d. R. Woolley, O.B.E., F.R.S., Astronomer Royal*)

Meridian Department.—The installation of the Cooke Reversible Transit Circle is complete and a team of observers is making observations with it for training purposes. Auxiliary apparatus, designed and constructed in the Electronics Laboratory, is complete and ready for installation in the pavilion ; this automatically punches on Hollerith cards the transit time whilst the observation is in progress, and saves the time hitherto spent in reading chronograph tapes. The Azimuth-Mark lenses are in position on the collimator piers. Work on the azimuth marks themselves is proceeding. The circle reading cameras are now functioning satisfactorily after a great deal of modification. A screw photomeasuring micrometer has been modified for use in the measurement of the films. The process takes a long time and it is hoped to find something faster. Screens have been fitted to the telescope, but the best combination of pure obstruction with diffraction-effects is still being investigated.

P.Z.T.—During the year 3019 stars were observed on 329 plates. These totals exclude plates on which the number of stars was too few to solve for the necessary plate constants. Prior to 15th March, the two-second impulses to the instrument were supplied from a Shortt Free Pendulum clock. After this date the observations were referred to a crystal clock at Abinger, the impulses being transmitted along a G.P.O. land line. In April the instrument was out of action for about a week while representatives of the makers dealt with some mechanical defects. They paid two further visits in September and October, when the instrument was out of action for about seven weeks. Plans to do part of the reductions on punched cards are well advanced. Plates already reduced by hand are included again in the punched data, so that the complete results obtained since the beginning of the programme will be available on Hollerith cards for subsequent analysis. All the necessary information has been punched. The interruptions which have occurred will not prevent use of the observations retrospectively, both for latitude and for time, as soon as the star-places have been smoothed by a year's consistent work ; time-results are expected to be serviceable back to 1956 March, for determining an adopted longitude, and latitude results probably back to 1955 November.

Time Service.—Astronomical observations for time determination have been made throughout the year using small transit C in the Courtyard Dome at Greenwich ; 232 observations were obtained on 179 nights. 137 observations were obtained on the Bamberg broken transit instrument at Abinger, but were not used for the assessment of clock performance.

Since 1950 it has been the practice of the Royal Greenwich Observatory to assess the performance of the clocks on the basis of a provisional uniform time (P.U.T.) from which variations due to polar variations and non-uniform rotation of the earth are eliminated. Corrections for polar variation used to be calculated from current latitude observations communicated by the U.S. Naval Observatory, and the divergences between the observed time, corrected for polar

variation, and a uniform scale of time derived from the quartz clocks, is expressed as the sum of an annual and a semi-annual term, and tabulated as the annual fluctuation. In accordance with the recommendations of the International Astronomical Union, the internationally-adopted corrections for polar variation and annual fluctuation have been used since 1956 January 1. The observed astronomical time, previously designated G.M.T., is now designated U.T.O. Provisional Uniform Time (P.U.T.), which incorporated the corrections determined at Greenwich, is replaced by U.T.2, which incorporates the international corrections.

In addition to the normal programme of reception and measurement of radio time signals, the Observatory has co-operated in the special quarterly programmes of time signal reception in connection with the experiment under the direction of M. Boella for the determination of travel times.

The time service has been controlled from Abinger, with Greenwich providing a reserve for certain signals. With the temporary removal from service of the Post Office G.B.R. transmitter for overhaul, the long-wave time signals have been radiated since October from Criggion G.B.Z.

Access to the basement and sub-basement floors of the Time Block, West Building, Herstmonceux, was obtained in October, and installation work was put in hand immediately. One Essen ring crystal, transferred from Abinger, was set going before the end of the year, and preliminary electrical work in the Clock and Control Rooms is proceeding steadily.

By courtesy of the Director, information relating to the quartz clocks and the caesium resonator at the National Physical Laboratory has been received monthly. The results obtained are being studied with interest, but are not so far being utilized, even indirectly, in the establishment of U.T.2 at the Royal Observatory. During the limited period that comparisons have been possible between the frequencies defined by the atomic resonator and by the U.T.2 time system there would not appear to have been any significant divergence.

Astrometry.—Observations ceased at Greenwich on the astrographic 13-inch refractor with the transfer of the remaining staff of the Astrometric Department to Herstmonceux in May: up to then 9 plates of Vesta and 19 of other minor planets had been secured. The instrument was dismantled in November and brought to Herstmonceux to await completion of its new dome.

The tests of plates taken with the Cambridge Schmidt telescope for astrometry have shown that star places can be observed on this instrument with about the same precision as on the Carte-du-Ciel astrograph, which has more than twice the focal length and less than half the linear field. Residuals from overlapping plates are being examined to see whether this performance can be improved by the application of corrections depending on position on the plate, on colour or on magnitude. Since the plates are curved to the focal surface during exposure they are thin, and as they do not flatten completely after the exposure, a limit is set to the precision attainable.

Mechanical overhaul of the 36-inch reflector was substantially completed in the spring at Greenwich. The N and S piers and polar axis were dismounted on November 22–23 and re-erected in the uncompleted dome at Herstmonceux by December 3; the rest of the telescope cannot be assembled until the dome is more nearly finished.

The new mounting for the 30-inch reflector (which shared the Thompson

mounting with the 26-inch refractor at Greenwich) was completed in October, and preliminary tests of the drive were carried out at the works of Messrs H. D. Barlow in November. The fabricated base, polar axis, fork and tube were erected in the new dome at Herstmonceux on December 4 ; final assembly awaits completion of the dome.

The dome built for a Schmidt camera yet to be designed will be used at present for a 20-inch reflector, formerly the property of Isaac Roberts, on loan from the Science Museum. This telescope, which has been in store for many years, was reconditioned during the autumn in the Observatory workshop and installed early in December on a temporary fabricated framework on top of the concrete pier intended for the Schmidt camera.

Solar Department.—The Sun was photographed in white light with the photoheliograph on 306 days during 1956. Negatives from the Cape Observatory were received up to September 30. Measurement of the combined series has been completed up to August 31 and copy for press of Greenwich Photoheliographic Results for 1955 has been prepared. Summary tables for 1953 and 1954 have been published in *Monthly Notices* and those for 1955 are in course of publication.

On 258 days the Sun was photographed in Hα light with the birefringent filter on the Newbegin 6-inch telescope and negatives for almost all these days were sent to the Fraunhofer Institute to be used in the compilation of daily maps of solar features. 117 solar flares were observed either with this instrument or with the spectrohelioscopes.

Records of atmospheric noise at a frequency of 27 Kc/s have been continued. 160 enhancements due to the effects of solar flares were recorded. A monitor of signal strength from a Paris broadcast transmitter (6·2 Mc/s) has been operated since July.

Current information on solar activity has been supplied on a routine basis as in previous years.

In conjunction with the Cosmic Ray Department a collection has been made of published and unpublished data concerning the solar flare of 1956 February 23 and its subsequent ionospheric, geomagnetic and cosmic ray effects. Forty photostat copies have been distributed to the various contributors and other individuals in many countries.

Nautical Almanac Office.—The 1957 editions of the annual publications of the Office and the four-monthly parts of the Air Almanac for 1956 September to 1957 August have been published during the year ; no changes in content have been made.

When a large amount of constant or nearly constant data, together with a large proportion of the Explanation, was omitted from the *Nautical Almanac* from the edition for 1942 it was proposed that the omitted material, perhaps with added data relevant to the Almanac, should be published in a *Supplement*. Preparation could not be started until well after the war, and even then changes in the method of calculation and proposed changes in the content of the *Nautical Almanac* made it preferable to defer publication. It has now been agreed that the Supplement shall be a joint *Explanatory Supplement* to both the *Astronomical Ephemeris* (the new name as from 1960 of the *Nautical Almanac*) and the *American Ephemeris*, and that the U.S. Nautical Almanac Office shall assist in its preparation. The form and scope of the publication were agreed during

the Superintendent's visit to U.S. Naval Observatory. Publication is not planned until 1959.

The new extended edition of the booklet *Interpolation and Allied Tables* has been published ; and copy for the companion booklet on *Subtabulation* has been prepared.

Royal Observatory, Edinburgh

(Acting Director, Dr M. A. Ellison)

Stellar Spectrophotometry.—Publications of the Royal Observatory, Edinburgh, Vol. II, No. 1 (" Further Results and Discussion for B1 stars ") by Dr R. Wilson appeared during the year.

Results for 16 stars of types O6–B0 are at present being analysed by Dr R. Wilson. A paper giving results and a general discussion is being prepared.

A paper describing an investigation into the variability of the Balmer lines in β Cephei has been published by Dr R. Wilson and Mr H. Seddon in *The Observatory*, **76**, 145, 1956.

It was reported last year that the measurement of the spectra of 18 stars of type B2 had been completed. These data have now been reduced. The 18 stars were all the stars of MK Type B2 accessible at Edinburgh and brighter than $5^{m}\cdot 0$, which was the limit set by the dispersion, the adopted slit width and the Ilford Astra VIII emulsion. The stars included 2 of luminosity class I, 4 of class III, 4 of class IV, 4 of class V showing normal Hα absorption and 4 of class V showing evidence of emission in Hα. The lack of balance in the programme due to the inclusion of only 2 class I stars became increasingly evident during the year and it was eventually decided to hold back the analysis until plates of 3 more B2 class I stars could be taken and reduced. Since the only available stars were between $6^{m}\cdot 0$ and $7^{m}\cdot 0$, it was necessary to change to a faster emulsion—Kodak 103aF—and to redetermine on this emulsion the Oe5 continuum, which is such an important item in the Edinburgh method of spectrophotometry.

The results for all 21 B2 stars are now completely reduced and it is expected that these, together with their analysis, will appear in a paper by Dr H. E. Butler and Mr H. Seddon during 1957.

During 1956, observational work with the 36-inch telescope and spectrograph has continued. In addition to the spectra mentioned above, further plates have been taken, mainly of types B3–A0. In all, 270 spectra have been obtained on 54 nights.

Two large items of new equipment were ordered in 1956. Messrs Hilger & Watts, Ltd. commenced work on a new Cassegrain stellar spectrograph, while Messrs Edwards High Vacuum Ltd. have almost completed the construction of an aluminizing and blooming plant large enough to coat the 36-inch mirror.

The spectrograph, delivery of which is expected in 1960, will be a grating instrument. A single camera lens of 13-inch focal length will be used with interchangeable Bausch and Lomb blazed gratings of 4-inch aperture ; it will be possible to photograph any region of the spectrum between 4000 A and 9000 A at 40 A/mm and any region between 4000 A and 7200 A at 20 A/mm. The collimator is of Cassegrain design and of 68-inch focal length. Other new equipment received includes a pen recorder and a pulse counting unit.

Both will be used for experimental work in direct-recording spectrophotometry.

Solar work.—Disk drawings of the Sun in white light were obtained on 171 days, and Hα observations were made with the spectrohelioscope on 174 days. Twenty-six flares were recorded during 203 hours of observation: 1 of class 3, 5 of class 2, 12 of class 1 and 8 of class 1^-. The scheme of flare classification, as adopted by the IAU at its meeting in Dublin, has been in use since 1956 January 1.

The recorder which shows the integrated level of radio atmospherics on a frequency of 24 Kc/s has been in continuous operation, and 107 sudden enhancements of atmospherics (S.E.A's) were recorded. This is the largest number of S.E.A's for any one year since the apparatus was installed in 1949, and it indicates the rapid rise in solar flare activity which has taken place with the approach to sunspot maximum. The yearly numbers of these sudden ionospheric disturbances recorded at Edinburgh since 1950 have been as follows:

Year	1950	1951	1952	1953	1954	1955	1956
S.E.A's	82	81	22	7	0	33	107

A notable record was obtained with the same apparatus on the morning of 1956 February 23 (*J.A.T.P.*, **8**, 291, 1956). At 0345 U.T. the integrated level of atmospherics on 24 Kc/s fell from the normal night-time strength to the daylight value in a period of about 5 minutes. This unique effect has been interpreted as having been caused by the sudden ionization of the D-region due to the impact of cosmic-ray particles within the night hemisphere of the Earth. These particles had their origin in the great solar flare which was observed from 0330 U.T. onwards at Tokyo and Kodaikanal. The time-interval (cosmic-ray maximum *minus* flare maximum) was in this case about 20 minutes. This is the shortest delay time recorded in the five cases where cosmic-ray bursts have been associated with 3^+ flares since the first of such coincidences was recorded in 1942.

A second long-wave receiver, similar in circuit design to the above, was installed during the year, and will be used during the I.G.Y. for the recording of S.E.A's on other frequencies.

A short-wave receiver has been in operation throughout the year for the recording of cosmic noise on a frequency of 18 Mc/s. Twenty-three sudden fade-outs of cosmic noise (S.C.A's) have been recorded with this set.

A striking example of a blow-off prominence was observed with the combined spectrohelioscope and spectrograph on 1956 May 18. Photometric and other measures of this phenomenon have been communicated in a short paper to *Monthly Notices*.

Some further plates of the spectra (Balmer lines Hα–Hε with H and K) of limb prominences were taken during the year with the spectrohelioscope and spectrograph, thus completing the programme begun three years ago. A careful investigation has been carried out of the instrumental profiles of the spectrograph for the first and second order spectra, using the same slit widths as for the prominence spectra. A laboratory source—the λ5571 line of krypton from a G.E.C. krypton discharge tube—was employed for this purpose. Spectrophotometric results are now available for 17 prominences. These comprise equivalent widths for all the above lines and corrected line profiles for Hα, Hβ

and Hγ in the same prominence regions. The mean profiles for Hβ and Hγ give a reasonably good fit for a Maxwellian distribution of atomic velocities at a temperature of 10 000 deg. K. The Hα profiles, however, indicate strong self-absorption effects and give values of the optical depth (C) ranging from 3 to 10. The number of emitting atoms in Hα is found to be of the order of 6000 per c.c. These results have been discussed by Dr M. A. Ellison and Mr J. H. Reid and will appear shortly in Vol. II, No. 2 of our *Publications*.

The Lyot-type Hα Heliograph, which has been under construction by the firm of S.E.C.A.S.I. at Bordeaux, is nearing completion. It is hoped that it will be ready for dispatch to the Royal Observatory, Cape of Good Hope, by 1957 April in readiness for operation there during the I.G.Y. Cinematograph projectors for the examination of the Heliograph films at Edinburgh were ordered during the year, and preparations are being made for the photometric examination of these films by means of the Kipp Star Actinometer.

Stellar photometry.—The programme of photometry of star clusters with the 16/24-inch Schmidt camera has been continued by Dr V. C. Reddish with the assistance of Mr J. H. Reid. During the year 22 plates on clusters have been obtained, most of 30-min exposure, some of two hours, reaching to 17^{m} with Ilford Process Pan plates and tricolour filters. The measurement of the plates for NGC 6940 has begun.

Dr Reddish has published papers on The Period–Luminosity Relation and Stellar Composition (*M.N.*, **116**, 533, 1956) and The Integrated Colour of Old Population I Systems (*The Observatory*, **76**, 68, 1956) and is continuing investigations into the rate of star formation in the early history of galaxies.

The Crawford Library.—The construction of a strong-room in the Observatory basement was completed by the Ministry of Works. To this room have been transferred some 800 volumes of early printed works, first editions and manuscripts. Here they are now housed in adequate security and under the best conditions of temperature and humidity. Suitable lighting has been installed, so that the books, with their unsurpassed bindings, may be seen to best advantage by interested visitors.

Tablets have been placed in the Main Library and in the strong-room to commemorate the founding of the Library and its gift to the nation by the 26th Earl of Crawford in 1888. Including all subsequent additions, the Library now contains 25,000 volumes.

Time-service.—The mean-time clocks, Riefler 258 and Leroy 1230, have maintained good rates. Building alterations to the Clock Cellar, attendant upon the installation there of the aluminizing plant, seriously disturbed the rate of Leroy in the last week of October. Riefler, which is mounted within the massive pillar of the 36-inch reflector, was not affected and its signals have been used throughout the year to regulate the Edinburgh clocks, time-gun and time-ball. Leroy has been kept on time in case of failure.

Seismology.—Our thanks are due, as in former years, to Mr E. Tillotson for undertaking the reduction of the Milne–Shaw seismograms and for answering correspondence relating to them.

Gravity Measurements.—Absolute measurements were carried out in July at the station in the Clock Cellar by R. Bruns and K. Marzahn, Deutsches Geodätisches Forschungsinstitut, Munich. Some relative measures were made in October by Mr J. G. D. Pratt, of the British Transantarctic Expedition.

Colloquia.—Three Colloquia were held during the year on the following subjects: Terrestrial Clouds (Mr P. E. Phillips), Photographic Emulsions (Dr E. A. Baker) and Atmospheric Tides and their Effects on Terrestrial Magnetism (Mr D. H. McIntosh).

Visitors.—Visiting scientists have included Dr R. J. Bray, Dr J. G. Davies, Professor G. Z. Dimitroff (Dartmouth College), Dr O. J. Eggen, Professor L. A. Mayer (Jerusalem), Professor Sherhag and students (Berlin), Dr R. H. Stoy and Dr R. v. d. R. Woolley. Members of the Edinburgh Astronomical Society were welcomed on June 9.

Personnel.—The post of Astronomer Royal for Scotland and Professor of Astronomy in the University of Edinburgh, rendered vacant in 1955 by the death of Professor W. M. H. Greaves, F.R.S., remained unfilled. The University lectures in Astronomy were delivered by Dr V. C. Reddish. Mr G. A. Ramsden joined the staff in June with the rank of Assistant Experimental Officer.

Royal Observatory, Cape of Good Hope

(*Director, Professor R. H. Stoy, C.B.E., H.M. Astronomer*)

Gill Reversible Transit Circle.—The observations for the *Second Cape Catalogue for* 1950.0, which were begun in 1951, were continued. The working list contains approximately 7000 stars and many of them have now received their full quota of eight observations, four in each position of the instrument. It is hoped that the observations for the remainder will be completed during 1957 or the winter of 1958.

During 1956, a total of 11 801 transits was observed. This includes 382 observations of stars during the day time and the following observations of bodies in the solar system :—

Sun	139	Mars	26	Neptune	28
Moon	41	Jupiter	34	Ceres	19
Mercury	68	Saturn	23	Vesta	17
Venus	117	Uranus	18		

The preparation of the next working list has been commenced. This list will be in five sections, the first section containing stars from the fundamental catalogues south of 30° N and the other sections relatively faint stars between $-30°$ and $-40°$, $-40°$ and $-52°$, $-52°$ to $-64°$, $-64°$ to $-90°$, specially selected to serve as standards in the reduction of photographic plates. The resulting catalogue is intended to form a southern extension of similar catalogues being prepared in the northern hemisphere.

Cape Photographic Catalogue for 1950.0.—Work on this project proceeds steadily, the position at the end of 1956 being as follows. The catalogue was published as far as $-56°$; ready for publication to $-64°$; positional measures complete to $-72°$; photometric measures practically complete to $-68°$. The zone $-72°$ to $-76°$ was ready for measurement while south of $-76°$ the meridian and photographic observations had been completed and the selection of the stars to be measured and the computation of the necessary standard coordinates were in hand.

Parallax programme.—The observations for the 1806 stars of the main part of this programme were completed in 1951 but a few extra stars have since been added at the specific request of individual astronomers. During 1956, 53 plates were taken with the Victoria Telescope of which 32 were for parallax and 21 for the determination of proper motion. These 21 plates were the last required to complete the programme for obtaining the proper motions in declination for all the 1806 stars in the original parallax programme. 28 plates were measured for parallax and 560 for proper motion in declination. Proper motions in declination have now been completed for all the stars for which parallax determinations were published in Volume XV of the Cape Annals. The probable error of these determinations, $\pm 0''\cdot 0028$, is considerably smaller than those for the previous series of measures due to the longer interval between the plates measured.

Proper motions.—68 plates were taken with the Astrographic Refractor in connection with the programmes, suggested by the 1953 Groningen Conference, for using existing astrographic material to find the proper motions of selected objects and of stars in a few specific areas. This programme was not stressed during 1956 because the poor condition of the axes of the telescope made precise guiding of long exposures very difficult. The main bearings are to be renewed early in 1957 and every effort will then be made to complete this programme as soon as possible.

Minor Planets.—Routine observation at approximately ten-day intervals of ten selected minor planets was begun at the end of March, in accordance with the programme suggested by the Russian astronomers of using such observations for controlling systematic errors in the KSZ, the new Catalogue of Faint Stars that is now being prepared. By the end of the year the following observations had been secured :

Ceres	16	Vesta	8	Melpomene	6
Pallas	13	Hebe	8	Laetitia	2
Juno	9	Iris	8	Harmonia	18

Stellar photometry.—Work on the *Second Bright Star Programme*, which includes all stars in the Yale Bright Star Catalogue between $-4°$ and $-64°$ together with a number of fainter stars from radial velocity and parallax lists, continued steadily throughout 1956. 3443 two-colour observations were made for it on 109 nights with the photoelectric photometer attached to the Astrographic Refractor. By the end of 1956, magnitudes and colours had been derived for 1250 stars, all of which had been observed at least four times. The internal standard errors of the resulting magnitudes and colours are $\pm 0^{m}\cdot 008$ and $\pm 0^{m}\cdot 006$ respectively.

During the year the observations of the standard stars being used for this programme were critically examined to see how far their assumed magnitudes and colours were being reproduced by the actual observations. It was found, as indeed had been anticipated from the excellent agreement of the individual observations of the programme stars, that this reproduction is good, though there is a small band width effect amounting to a maximum of $0^{m}\cdot 02$ for stars of extreme colour. Such an effect is not surprising because the assumed standard magnitudes were derived from observations made photographically with a Fabry

photometer. The formulae for transforming the observed magnitudes and colours into the Johnson *B*, *V* system were also re-investigated but no significant change to the formulae already in use was found necessary. The natural colour systems of the visual magnitudes observed with the photometers on the Astrographic and Victoria Telescopes appear to be very close to that of Johnson's *V*. It has therefore been decided to adopt this system in future Cape publications.

3277 observations were made on 105 nights with the photoelectric photometer attached to the Victoria Refractor for the main E region programme. This programme, which was planned to consolidate the work on the brighter standard stars in the E regions, is now virtually complete down to the eleventh magnitude for six of the nine regions. It is anticipated that the remaining regions, E5, E6 and E7, will be completed during the coming winter so that it is hoped that by the end of 1957 definitive magnitudes for all the regions will be available both on the original SPg, SPv system and on an ultraviolet-free pg, V system which will be as close as possible to the Morgan-Johnson *B*, *V* system. Ultraviolet colours U-B are being measured as a routine for all stars brighter than 10·0 SPg and these measures, supplemented by others made with the Astrographic Refractor and the Radcliffe Reflector and reduced to the same system, will provide ultraviolet colours on a " refractor " (or " silver reflector ") system for almost all the standard stars. Unfortunately, it does not seem possible to make simple accurate transformations between this system and the Morgan-Johnson *U–B* system, which refers to measures made with an aluminized reflector.

144 photoelectric observations were made on four nights with the Astrographic Refractor for the programme of determining *U–B* colours for stars brighter than $7^{m}{\cdot}0$ in the E regions. 296 three-colour observations of B type stars were made on 12 nights with the Victoria Refractor at the request of the Radcliffe Observer. These were all stars being observed spectroscopically at Pretoria.

As the observations with the Victoria Telescope for the main E region programmes are now nearly complete, a new working list of about 850 stars has been drawn up. This list includes all the Johnson stars south of $+10^{\circ}$, the stars in the new radial velocity observing list and the stars in the Cape parallax programme which have not yet been observed photoelectrically and are bright enough to be included in the Henry Draper Catalogue. The observations are being made in three colours and E region stars are being used as standards. Observing began in October. By the end of the year, 1221 observations had been made on 39 nights and magnitudes and colours had been derived for 52 stars, all of which had been observed at least four times.

136 pairs of plates were obtained with the Photometric Cameras for the programmes begun in 1952 December. 92 of these pairs were for the two zone programmes and 42 for comparing the C regions and the Kapteyn Selected Areas at $+15^{\circ}$ with the E regions at -45°. The observations are now complete for the -64° and -68° zone and only a few pairs of plates in the difficult winter months are required to complete the other two programmes. 45 397 images were measured with the modified Schilt Photometer. Of these 27 468 on 39 pairs of plates were for the -64° to -68° zone, 10 480 on 27 pairs of plates were for the $+15^{\circ}$, -45° comparison programme and the remaining 7449 were on schraffierkassette plates of the E regions taken some years ago with the Radcliffe Reflector.

Variable stars.—Mr R. P. de Kock continued the programme of observing long period variable stars which he began twenty-four years ago. During 1956

he made 6364 observations or 181 stars with the 6-inch telescope. He also kept a special watch on T Orionis and on two "flare" stars, 013418 UV Ceti and 203501 AE Aquarii.

In the course of the routine radial velocity measures Dr Evans noticed that HD 16157 (or CZC 1209, HD spectral type K5) had a variable velocity with a range of over 55 km/sec. Photometric observations with the Victoria Telescope begun late in 1956 showed that the star also varied in brightness by about 0·20 of a magnitude. The provisional light curve is characteristic of an eclipsing binary showing only one minimum, the eclipses being partial and the components non-spherical. The period is close to 1·5609 days or twice this, though the radial velocities so far obtained support the shorter period. Neither the B–V nor the U–B colour vary appreciably. The B–V colour is $+1{\cdot}36$ and the visual magnitude, V, at maximum brightness is 8·73. With a trigonometrical parallax of 0″·083—the mean of two determinations given in the *Seventeenth List of Cape Parallax Determinations*—this gives an absolute magnitude of 8·3. Few dwarf eclipsing binaries of such late type appear to be known. If the parallax quoted is correct, this may be the nearest eclipsing binary known, as the accepted parallax of Castor C is 0″·072.

Guest investigator.—Dr Halton C. Arp completed the gathering of material for a population study of the Small Magellanic Cloud which he began in 1955 November. During his stay at the Cape Observatory, Dr Arp used the Victoria Refractor to obtain 193 long exposure photographs and over 400 three-colour photoelectric observations. Included in the photographs were (1) a series of 3-hour exposures covering the whole area of the SMC in each of the photographic, photovisual and ultraviolet wavelengths intended to provide magnitudes down to about 16^m in V and 18^m in B and to tie together all the separate photoelectric sequences that have been set up in various areas of the SMC, (2) 76 pairs of photographic and photovisual plates with an average exposure of 90 minutes centred on two special areas in the SMC for obtaining two-colour light curves of as many cepheids in the two square degrees covered by the plates as it seems desirable or feasible to measure, and (3) a series of plates of Omega Centauri and 47 Tucanae intended for studying the long period variables in these clusters. This series of plates is being continued at approximately ten day intervals by Mr Lourens.

The photoelectric observations were intended primarily to provide magnitude standards in the vicinity of the SMC and to tie these magnitudes firmly to the Morgan–Johnson B, V system. As it did not prove possible to tie the refractor ultraviolet observations to the aluminized reflector system of the Morgan–Johnson U, observations were made to define as closely as possible the characteristics of the observed three-colour system as regards luminosity classes and reddening. Particular attention was given to stars of luminosity class I.

Radcliffe section.—During the early part of the year, the greater portion of the observing time with the Radcliffe Reflector allotted to the Cape was used for the radial velocity programme of stars with large parallax or proper motion. Later in the year, however, more of the time was used for direct photography and to obtaining spectra of selected extragalactic and gaseous nebulae, while all the time available during October and November was devoted to photoelectric photometry. Altogether 565 spectra were obtained for the radial velocity programme, 33 spectra and 27 direct photographs for the nebular programme and 296

photometric observations. 664 spectra were measured for the radial velocity programme and 18 for the nebular programme.

The first radial velocity programme was terminated in March. The data for 339 programme stars which had been adequately observed and for which the derived radial velocity appears reasonably constant have been prepared for publication while the remaining stars for which more observations appear desirable or for which a variable velocity is suspected have been transferred to a new working list. Most of the other stars in this new list were selected on account of appreciable parallax or proper motion. It thus forms a logical extension of the earlier list, but the stars are, on the whole, rather fainter. Stars in the South Galactic Cap suggested by Professor Bart J. Bok and about a dozen stars each from the galactic clusters NGC 2516 and 2547 are also included in the list which altogether contains about 350 stars. By the end of the year, radial velocities depending on a minimum of four plates had been derived for 53 of these stars.

The 339 stars prepared for publication include many of the nearest stars in the southern sky. As good magnitudes and colours determined photoelectrically at the Cape are available for all the stars, it has been possible to construct for them an absolute luminosity—colour diagram and to use it to derive spectrophotometric parallaxes for about one half of the stars. The space motions for these stars are also being calculated.

Among the stars for which a variable velocity was found or suspected are three fairly definite spectroscopic binaries, HD 16157, 118261 and 154426. HD 16157 has already been mentioned under *Variable stars*. HD 118261 is also probably fairly important as it is a known visual binary (I 365) with an orbit by van den Bos. The spectroscopic binary characteristic appears, however, to be due to one of the components.

Using the Newtonian spectrograph, Dr Evans managed to obtain measurable spectra of five regions in NGC 253. This extragalactic nebula is of special interest since it is possible to identify the nearer edge and to trace out the spiral arm system. The spectrograms show that the system is rotating with the arms trailing.

A start has been made with the production of a Cape atlas of southern extragalactic nebulae in the form of enlarged prints from selected plates taken with the Radcliffe Reflector. Each print will be accompanied by a short description and commentary. The enlargements for the prototype have been made by Mr Charles Field, a local professional photographer. It is intended to offer these prints for sale to interested astronomers at cost.

Miscellaneous.—36 other pairs of plates were taken with the Victoria Telescope for various purposes during the course of the year. These include 24 for Dr Arp's programme on the long period variables in two globular clusters, 3 of Kapteyn selected areas and 9 of variable star or other areas for which chart plates were required.

69 observations of 38 occultations were made with various telescopes at the Observatory. Of these 58 were disappearances at the dark limb, 9 reappearances at the dark limb and 2 reappearances at the bright limb.

The Sun was photographed on 344 days, two photographs being taken each day except six. All the photographic plates have been sent to Herstmonceux for measurement.

Armagh Observatory

(*Director, Dr E. M. Lindsay*)

Dr Öpik continued his research on the physical theory of meteors. He developed a numerical theory of micrometeors and applied it to the frequency of diameters of cosmic spherules from deep sea clay. He has made theoretical studies of the surface conditions and atmospheres of Venus and Mars. With Mr Grossie he began a study of star chains and dark globules on ADH plates of the Eta Carinae region using the Iris Diaphragm photometer.

Dr Lindsay continued using the Armagh Schmidt telescope on variable star fields. A survey of clusters in the Small Magellanic Cloud was made on existing ADH plates. Leaving for the Boyden Observatory in July, he carried out observational programmes there. With the 60-inch Rockefeller reflector, photoelectric observations in two colours were made on southern eclipsing binaries. Observations of FU Arae, commenced in 1954, were completed and observations of SZ Sculptoris and AS Eridani almost completed. With the ADH and prism a survey for emission objects in the outlying regions of the Small Magellanic Cloud was completed. The survey was continued towards, in, and around the Large Cloud, the greater part of this programme being completed. The same regions were covered by direct 30-min exposure blue and red plates; these are being used for magnitudes, colours, star counts and a cluster survey. Exposures of 1 hour on the same regions were made with the 10-inch Metcalf telescope.

The meteorological observations were continued by Miss Grew.

Contribution No. 17 and Leaflets Nos. 36–44 have been distributed. Contributions Nos. 17–19 have been published: No. 17 "Emission Objects in the Small Magellanic Cloud showing the N_1N_2 Nebular Lines" by E. M. Lindsay (*M.N.*, **115**, 248, 1955); No. 18 "Clusters in the Small Magellanic Cloud" by E. M. Lindsay (*Irish Ast. J.*, **4**, p. 65); No. 19 "Interplanetary Dust and Terrestrial Accretion of Meteoric Matter" by E. J. Öpik (*I.A.J.*, **4**, p. 84). Other publications are "The Age of the Universe" by E. J. Öpik (Report of the Smithsonian Institution, 1955); "The Cosmic Rhythm" by E. J. Öpik ("The Pen in Exile", London, 1956). A paper on "A Catalogue of Emission Objects in the Small Magellanic Cloud" by E. M. Lindsay has been accepted for publication in the *Monthly Notices*.

Dr Öpik continued to edit *The Irish Astronomical Journal*, published by the Irish Astronomical Society. Volume **4**, Nos. 1–4, of the Journal have been published, completing the seventh year of this periodical.

Dr Lindsay attended a meeting of the Boyden Observatory Council at Bonn in May where it was agreed to continue the operation of the Boyden Observatory for a further ten years from 1956 July 1. Dr Öpik delivered a lecture to the Royal Irish Academy in March on "Results from the Arizona Expedition for the Study of Meteors" and to the Dublin Institute of Advanced Studies in May on "Terrestrial Accretion of Meteoric Matter". He participated in the series of meetings arranged by the Royal Astronomical Society at Bristol in July.

Dr Lindsay was on leave of absence at the Boyden Observatory from July until the end of 1956 during part of which time he was Acting-Director. Dr Öpik was given leave of absence to join the University of Maryland as Visiting Professor for a period of six months beginning 1956 December 1. His work there consists

of meteor research at the Department of Physics and in delivering a course of lectures on " The Physics of Meteors and their Cosmic Relationships ".

Cambridge Observatories

(Director, Professor R. O. Redman, F.R.S.)

Solar Research.—Dr Blackwell has completed measurement of the brightness and polarization of the zodiacal light between elongations 21° and 31°, from photographs taken by him in 1955 from an aircraft over the Pacific Ocean, near Fiji. The results have been interpreted in terms of electron densities in interplanetary space. The angle between the ecliptic and the axis of symmetry of the electron cloud for this range of elongation appears to be less than 1°.

Drs Blackwell and Dewhirst have compared the predictions and requirements of the accretion theory of the solar corona with the results of observation. In a paper communicated to the Society they conclude that even with reasonable modifications the theory appears unable to satisfy the observations, and that on present evidence accretion is not likely to be an important mechanism in the corona.

Dr von Klüber has nearly completed measurement and reduction of photographs of the corona taken by him at the 1952 eclipse (six images in each of three planes of polarization, six unpolarized). He has also made preliminary investigations with regard to equipment and observing sites for the 1958 and 1959 total solar eclipses.

First tests of the newly constructed solar magnetograph were started by Dr von Klüber and Mr Beggs in July. In principle the magnetograph follows H. W. Babcock's design, but some changes of detail have been made to suit local conditions, and the instrument is still without its scanning mechanism. Using a long spectrograph slit (1·7 min of arc) fields down to about 1 gauss can be detected. If the area covered by the slit is made smaller, to give more resolution on the Sun's surface, the sensitivity of the apparatus is correspondingly diminished. Examining areas of disk approximately 4 seconds of arc square, comparatively large local magnetic fields, up to about 100 gauss, can readily be seen, and these are found often to appear over regions where the disk shows no visible disturbance in white light. This project is supported by a D.S.I.R. grant.

Dr Z. Suemoto (Tokyo) has completed an investigation for which he obtained the material at Cambridge in 1953. He has measured the profiles of a few well-isolated and faint Fraunhofer lines in the red, using a Fabry–Perot interferometer giving a resolving power about 6×10^5. The results have been interpreted in terms of a circulation of matter in the solar photosphere, vertical upward motion in granules being converted into horizontal motion at about $\tau = 0{\cdot}4$ and finally changing into downward motions back to the convection layer.

Drs Blackwell and Dewhirst have constructed an 11-inch telescope and camera for photographing solar granulation from a balloon. In November they took this to Paris, where Dr Blackwell and Dr A. Dollfus (Meudon) made a first flight from the Meudon Observatory, taking some hundreds of photographs at a height of about 20 000 ft. Despite trouble with the camera shutter some of the photographs show granulation at least down to about 1·5 sec of arc. Apart from the shutter the apparatus behaved well and the results justify a second flight,

which is planned for March. The work is supported by a Royal Society Government Grant.

17-inch Schmidt telescope.—Dr Dewhirst and Mr Argue have been investigating what performance a Schmidt telescope can give in astrometry and in-focus stellar photometry. The astrometric programme is continuing in cooperation with the Royal Greenwich Observatory, the results so far being quite encouraging. Progress in the photometric investigation has been much assisted by a Sartorius iris-diaphragm photometer, which the Royal Greenwich Observatory have kindly lent to Cambridge for a period of about 15 months.

There is an error in magnitude from well-exposed photographic images obtained with this telescope (F/3·8), of about $0^m{\cdot}03$ for a focus error of 50 μ, varying approximately as the square of the focus error. Measurement of a deformed plate in the plate-holder shows that the emulsion fits the focal surface to within 12 μ. Mr Argue has found that it is not difficult to obtain good internal consistency on one plate, with a probable error of about $0^m{\cdot}03$ from one image, but in transfers of scales and zero points from one field to another errors of $0^m{\cdot}1$ or more can sometimes arise from comparatively small changes of seeing, focus, or guiding. An intensive three-colour photometry of SA 8 is being carried out as a part of this investigation.

36-inch reflector.—Following the experiments mentioned in the last Report both dome and telescope tube have been provided with strong controllable ventilation, and a refrigerating unit has been made for controlling the principal mirror temperature by day. The dome and its walls have been painted white. There is little doubt that these changes and additions make a substantial improvement to the optical performance of this particular telescope. Probably most reflectors would benefit by similar ventilation, etc., although of course the improvement cannot affect scintillation produced well outside the dome. Given suitable ventilation a telescope tube with a closed wall appears to be better than an open one.

The three-colour stellar photometer at the coudé focus has been used by Mr Willstrop for quasi-monochromatic photometry in three wavelength bands 200–300 A wide. The quasi-monochromatic equivalents have been determined for the old international pg, pv and the *U*, *B*, *V* systems. An improved photometer, using a grating and mirror optics instead of quartz prisms and lenses, and three photomultipliers instead of one, is being brought into service. The electronic design and construction has been carried out by Mr Beggs.

Dr Fellgett's multiplex spectrometer has been tested at the coudé focus. The performance was encouraging, particularly with regard to the smooth driving of the interference fringes, but the energy efficiency of the beam-splitter needs to be increased. It has been confirmed that a fully balanced system is needed to overcome the effects of brightness scintillation, but that the shear of the interfering wave fronts can be kept sufficiently small to make the interference insensitive to phase scintillation. Some of the necessary modifications have already been made to the apparatus and further tests should follow shortly.

Optics.—Dr Linfoot and Dr E. Wolf (Manchester) have completed their examination of the phase distribution in and near the central nucleus of an aberration-free diffraction image and the results have been published. Dr Linfoot has also completed, with Dr G. Black (Manchester), the investigation into the effect of combined spherical aberration and defocussing on the information

content of optical images, and they have applied the results to obtain approximate tolerance limits for these aberrations in an F/2 system working with a photographic emulsion of specified spread- and noise-characteristics.

The effect of chromatism on the quality of optical images formed by astronomical telescopes has been examined from the information point of view by Dr Linfoot and Miss G. L. Story, in selected special cases.

Aspheric grinding and polishing of the corrector plates of the 12–15 inch two-plate Schmidt–Cassegrain camera have been completed. Experiments in making optical flat mirrors of chromium plated steel have been resumed.

Other investigations.—Professor Stratton and Dr Beer are investigating the recent spectrum of N Her (1934), using copies of spectrograms taken in 1954–55 by Dr G. H. Herbig at the Lick Observatory. These cover several of the short periods, $0^{d}\cdot19$, which the star now shows as an eclipsing binary. Dr Beer has also continued work on Radcliffe Observatory spectrograms of the peculiar A star θ'Mic.

Professor Redman has measured line intensities in spectrograms from the Dominion Astrophysical Observatory, Victoria, B.C., of bright stars near type Ko. The difference in line strength between the "strong" and "weak" line stars of Miss Roman appears to be at most only a few per cent. Since general line strengths near Ko change about 5 per cent for a change of one-tenth of a spectrum class, a satisfactory quantitative investigation of "s" and "w" stars needs very accurately determined types, as well as more material than was available in this case. A brief investigation based on the same spectrograms has shown that any satisfactory quantitative examination of the 4200 A *CN* band would need independent data on the intrinsic luminosities of the stars.

Buildings.—The interior of the western end of the Solar Physics Building has been remodelled, with a very satisfactory improvement in accommodation.

Colloquia.—The Observatory Club held 13 colloquia during the year. Speakers from outside Cambridge were Dr and Mrs K. H. Böhm-Vitense, Dr R. d'E. Atkinson, Dr R. H. Garstang, Dr R. Hanbury Brown, Professor Y. Öhman, Dr A. Keith Pierce, and Dr Olin J. Eggen.

Staff.—Dr G. I. Thompson joined the staff on October 1 as Junior Observer. Miss C. P. Wilks joined as a computer at the beginning of the year.

Cavendish Laboratory

(*Director, Professor N. F. Mott, F.R.S.*)

1. *The Mullard Radio Astronomy Observatory.*—The radio astronomical work of the laboratory will, during the course of the next few years, be gradually transferred to a new observatory, the construction of which has been made possible by generous grants from Mullard Ltd. and the Department of Scientific and Industrial Research. The new site, which will be known as the "Mullard Radio Astronomy Observatory", is situated six miles south-west of Cambridge; the area of land available is considerably greater than at the present site, and it is hoped that the local electrical interference will be less.

A laboratory building has now been completed, and work has started on the construction of two large instruments. The first of these is a new type of interferometer for radio star observations, and the second is an enlarged version

of the "pencil-beam" instrument developed by Blythe; it will be used on a wave-length of 7·9 m for the study of the galactic background radiation.

2. *Solar*

(*a*) *The outer corona.*—Further observations were made during 1956 June of the occultation of the Crab nebula by the solar corona. By making observations with interferometers whose axes were inclined at different angles to the solar axis, it was possible to show that the scattering produced by the coronal irregularities is anisotropic.

The position angle of the direction of maximum scattering is consistent with irregularities having a disposition like an extension of the polar rays (1). The presence of an extensive general magnetic field would provide an adequate mechanism for the maintenance of irregular structure in the region 5–20R_0; the origin of such irregularities is readily explained in terms of the outward diffusion of matter from the chromosphere, but is less easy to account for if the corona is regarded as due to the accretion of interstellar matter.

The scattering has shown a tendency to increase during the solar cycle, but it appears that the irregularities in the range 5–20 R_0 do not exhibit such marked solar-cycle changes as is apparent in the inner regions.

(*b*) *Routine observations.*—Regular observations have been maintained of the intensity of the solar emission on wave-lengths of 1·7 m 3·7 m and 7·9 m.

3. *Radio stars*

(*a*) 1·9 *m survey.*—The large four-aerial interferometer has been used on a wave-length of 1·9 m in a new survey of radio stars. At this wave-length the primary resolving power is increased by a factor of four compared with the earlier survey (2) and the effects of confusion between adjacent sources are therefore reduced. The increased resolution of the two interference patterns also allows a considerable improvement in the accuracy of location of sources, and enables smaller angular diameters to be determined.

The new survey is intended to provide more conclusive evidence on the spatial distribution of the sources, and it is hoped that the positions of a considerable number of sources may be found with sufficient accuracy to warrant a more extensive optical search for related objects.

The observations have now been completed over a large area of sky and the reduction of records is in progress.

(*b*) *Lunar occultation of the Crab nebula.*—Observations on 1956 January 24 of the lunar occultation of the Crab nebula were made at wave-lengths of 3·7 and 7·9 m (3). The distribution of "radio brightness" was found to differ at the two wave-lengths and this result suggests that there may be a radial variation of the magnetic field or the energy spectrum of the high energy electrons which are probably responsible for both optical and radio emission from the nebula (4).

The results at 3·7 m also showed the absence of any marked fine structure in the "brightness" such as might be expected from the irregular features observed optically.

The determination of the interval between immersion and emersion enabled an estimate to be made of the refraction occurring in the lunar atmosphere; this observation has been used to derive upper limits for the density of various possible models of the lunar atmosphere (5). For most of the models considered the density cannot exceed 3×10^{-13} of that of the terrestrial atmosphere.

(*c*) *The spectra of radio stars.*—An attempt has been made to determine the absolute spectra of the four most intense radio stars by means of observations at wave-lengths of 60 cm, 1·4 m, 3·7 m and 7·9 m (**6**). In each case absolute calibration of the receiver sensitivity was provided by a resistance heated to various temperatures between −183 deg and +100 deg C; the observations were made with small aerials whose directivities could be computed.

A new series of observations of a larger number of sources has been made at the extreme wave-lengths of 60 cm (**7**) and 7·9 m (**8**); in these observations aerials of larger directivity were employed, and their directivity was found from observations of the source in Cygnus.

Whitfield (**9**) has combined these new results together with those of all previous surveys to try and establish the most reliable spectra for some 30 sources. The accurate absolute figures which are now available for the two intense sources have made it possible to scale those surveys which did not include good absolute calibration, and obtain figures for many sources over a wide range of wave-lengths. The points derived in this way fall on remarkably smooth curves.

(*d*) *The distribution of the " brightness " across two intense sources.*—Interferometric observations at a wave-length of 60 cm have been made to determine the distribution of " brightness " across the intense sources in Cygnus and Cassiopeia (**10**). The results for both sources agree closely with those made at lower frequencies.

4. *The general radiation*

(*a*) *Spectrum.*—An investigation has been made of the spectrum of the background radiation in different parts of the sky, using aerials having identical reception patterns at wave-lengths of 1·7, 3·7 and 7·9 m (**6**). Except in regions very near to the galactic plane the spectrum was found to be closely the same in all directions, with a brightness temperature which varied as $\lambda^{2 \cdot 5 \pm 0 \cdot 1}$.

This result has suggested that the emission is caused by relativistic electrons which circulate throughout the " halo " and that a magnetic field must exist in the halo which is about one-fifth of that near the plane (**6**).

(*b*) *7·9 m survey.*—A survey of the background radiation at a wave-length of 7·9 m and having a resolution of about $2\frac{1}{2}^\circ$ has now been completed; the observations have been reduced to give a map of the sky between declinations -20° and $+65^\circ$ (**11**).

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University Observatory, Glasgow

(*Director, Professor W. M. Smart*)

Dr Tannahill has continued his work on the movements of the A-type stars relative to the Sun. Whole-sky solutions for these stars (spectral groups B8–A4) as a whole give a parallactic motion of 17·88 km/sec towards an antapex at galactic longitude 200°·4 and galactic latitude −22°·7. The spectral sub-groups B8–B9, A0, A1–A4 agree with this substantially in direction, but show a marked decrease in speed with advancing spectral type, from 20·47 km/sec for the B8–B9 group to 15·24 km/sec for the A1–A4 group. Solutions have also been obtained with the stars arranged in four distance-groups. The asymmetry of the parallactic motion, in the north and south galactic hemispheres, referred to in the last report, has been verified. A grouping of the data according to distance from the galactic plane suggests that this asymmetry may be due to a progressive increase in the Z-component of the parallactic motion as the true central plane of the galaxy is approached (it is assumed that this plane is about 50–100 parsecs south of the Sun). These results are being prepared for publication.

Dr Ovenden has continued his investigations on the structure of the solar system, partly in collaboration with Dr A. E. Roy. He has also been examining the relationship of the radial velocities of late-type stars to the two-streams theory.

The Director has completed a book on "The Combination of Observations" which will be published shortly by Cambridge University Press.

University of London Observatory

(*Director, Professor C. W. Allen*)

Photoelectric photometry.—Photoelectric observations to detect light variations in spectroscopic binary stars have been initiated by Mr T. Kiang. The programme includes about fifty stars, and at least one variable (BS 1078) has been detected.

Laboratory spectroscopy.—Dr A. S. Asaad has completed his observations of absolute oscillator strengths of lines in the following neutral atoms, Al (2), Si (1), Cr (67), Mn (37), Fe (78), Co (62), Ni (40), Cu (138), Ga (2), Sn (4), Ag (1), Pb (5), Bi (1). The number of lines measured in each spectrum is shown in parenthesis. The Director and Dr Asaad have used these measurements for clarifying the excitation potential effect mentioned in the last report. Mr E. W. Foster has used a water-stabilized arc to complete a set of absolute oscillator strength measurements on four O I lines. Values have been compared using arc temperatures ranging from 8200 deg K to 12 500 deg K. A new technique for injecting required elements into the water-stabilized arc has been developed. This has been used to excite the spectra S I, S II, Cl I, Cl II, and possibly A I, under controlled conditions.

Use of telescopes.—The Radcliffe 24-inch refractor was used on 6 nights for photographing minor planets, 5 nights for photoelectric scanning of visual double stars, 4 nights for photoelectric observations of Jupiter's satellites,

and 27 nights for photoelectric observations of spectroscopic binaries. The Wilson 24-inch reflector and smaller telescopes have been used by students and visitors.

Instrument construction.—Mr E. W. Foster is designing two new spectrographs now under construction. A new optical grinding spindle has been constructed in the workshop and on it a 12-inch spectrograph reflector has been produced. Dr P. A. Sweet has constructed a photoelectric device for scanning the two components of a double star.

Theoretical work and analysis.—Dr P. A. Sweet has been working on a theory of solar flares. Dr R. H. Garstang has continued his investigations on the computation of transition probabilities of lines. A study of methods of calculating electric quadrupole line strengths was completed and applied to the d^4 and d^5 configurations. Detailed calculations on magnetic dipole radiation in Fe III and on electric quadrupole radiation in Fe V were completed, and good progress made with work on electric quadrupole radiation in Fe III. The Director has made a statistical analysis of solar decimetre-wave radiation in the period 1947–54 in order to segregate the quiet component from the slowly varying component.

Publications.—The following papers have been published during the year:

C. W. Allen and A. S. Asaad, "Atomic oscillator strengths and excitation potentials", *M.N.*, **115**, 571, 1955.

C. W. Allen, "Influence of solar atomic emission on the orbits of interplanetary particles", *The Observatory*, **76**, 101, 1956.

C. W. Allen, "Solar sources of ionospheric regions", *Solar Eclipses and the Ionosphere*, p. 150, Pergamon Press, 1956.

C. W. Allen, "Coronal photometry at the eclipse of 1954 June 30", *M.N.*, **116**, 69, 1956.

R. H. Garstang, "The effect of configuration interaction on forbidden line strengths", *Proc. Camb. Phil. Soc.*, **52**, 107, 1956.

R. H. Garstang, "Transition probabilities of auroral lines", *The Airglow and the Aurorae*, p. 324, Pergamon Press, 1956.

Staff, students, and visitors.—There have been no staff changes. Dr A. S. Asaad completed his Ph.D. work in October and has returned to Helwan, Egypt. 10 undergraduate students have been taking regular lecture courses or practical astronomy since October. Professor V. C. A. Ferraro, Dr L. Mestel and Dr J. Ring have been visiting speakers to the observatory colloquia, and there have been 183 afternoon and evening visitors.

Royal Radar Establishment, Ministry of Supply, Malvern

An attempt has been made to measure the intensity of the radio spectral line of galactic deuterium at 327 Mc/s (1). An aerial of 25 ft diameter was directed towards the galactic centre in order to observe the line in absorption against the bright background radiation in this direction. The receiver frequency was swept in steps of 10 kc/s over a range of 100 kc/s with an integration time of 5 minutes at each frequency. Analysis of the results, after rejection of those showing interference, led to the conclusion that the aerial temperature corresponding to the absorption line must be less than 0·1 deg K, and that the abundance of deuterium consequently does not exceed 1/2000 that of hydrogen.

In order to increase sensitivity a larger aerial and an improved receiver have been constructed. The aerial has a parabolic reflector of 45 ft diameter; this radio telescope has been designed with sufficient accuracy to work at wavelengths down to 10 cm.

To provide a standard-temperature noise source for use with 10 cm radiometers, Hughes (**2**) has made an absolute calibration of an argon discharge tube. The effective temperature of the discharge tube was determined to an accuracy of 2 per cent.

The study of high speed shock waves is of interest in relation to various astrophysical phenomena, and a shock tube of 50 ft length has been constructed. The velocity of ionized shock waves has been measured by a radio reflexion method (**3**).

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Jodrell Bank Experimental Station, University of Manchester
(*Director, Professor A. C. B. Lovell, F.R.S.*)

The radio telescope.—The main structural steel work of the radio telescope was completed by the end of 1956. The sheeting of the paraboloidal bowl with the steel reflecting membrane was commenced in the autumn and had reached a diameter of about 86 ft by the end of the year. Final arrangements were made for the Ward Leonard driving system and it is expected that the telescope will be in its fully steerable operational condition by midsummer 1957. The associated electronic and recording apparatus for the investigation of the galactic and extragalactic radio emissions has been substantially completed, and good progress has also been made with the long pulse radio echo apparatus for the planetary investigations. A description of some of the scientific aspects of the telescope and of the problems on which the instrument will be used was given in the 47th Kelvin Lecture (**1**).

Galactic and extragalactic radio emissions.—(i) 92 *Mc/s survey.*—The pencil beam survey at 92 Mc/s, using the 218 ft transit radio telescope with its 3° beam (**2**), has been completed over the region declination 26°N to 70°N. The sensitivity is such that over much of this region the analysis of observations is limited by confusion, and some of the fine structure is difficult to interpret. To assist in interpretation, an interferometer with lobe spacing 22 min of arc has been constructed, using the 218 ft radio telescope in conjunction with a dipole array; the size of the latter is such that the sensitivity of the pencil beam survey has been retained. Observations with this equipment are now in progress.

A preliminary comparison of the 92 Mc/s pencil beam records with those previously obtained at 158 Mc/s—at which frequency the beamwidth of the 218 ft radio telescope is 2°—shows the expected agreement between the general features, and extraordinarily close correlation of the detailed structure. This now enables a large number of sources recorded at 158 Mc/s, but previously considered doubtful, to be regarded as certain.

(ii) *Diameter of the radio stars.*—At the beginning of 1956 the rotating-lobe interferometer was in use at 158 Mc/s in conjunction with the 218-ft transit

paraboloid, and a small aerial 20 km to the east. At this base line of λ10 600 the observations of weak discrete sources were difficult because there was some loss of signal-noise ratio in the radio link. The experiment was continued until sufficient records were obtained for an averaging technique to be used (3). Observations then ceased, to permit development work on the radio link.

Interferometer equipment for use with the steerable radio telescope has also been under construction this year. The new instrument will employ three remote stations, each having fully tiltable aerials of 200 m^2 aperture. Two of these stations will have radio links incorporating the improvements developed with the earlier instrument.

(iii) *The structure of the Cygnus and Cassiopeia radio sources.*—Measurements have been made of the apparent angular diameters of the intense sources in Cassiopeia and Taurus on a wave-length of 10·7 cm, using two paraboloidal aerials of 10 ft and 25 ft diameter respectively. East–west base lines up to 700 wave-lengths have been used. The results obtained (4) show that the diameters at this frequency do not differ by more than 20 per cent from those obtained at meter wave-lengths.

A programme of measurements on the structure of the intense radio sources in Cygnus and Cassiopeia was continued, using a three-station phase-sensitive interferometer. This instrument was operated on a frequency of 127 megacycles and measurements were made with aerial spacings of up to 2000 wave-lengths in position angle 090°. The amplitudes and arguments within the first three maxima of the Fourier transform of the Cassiopeia intensity distribution were determined along this axis. The argument and amplitude of the corresponding function for the Cygnus source was also determined over the same range of aerial spacings. The results confirmed earlier interpretations (5) of the duplex nature of the Cygnus source and yielded an intensity distribution for Cassiopeia in an east-west direction which showed the presence of a weak off-centred background source of 10 min diameter. A further series of measurements was undertaken to establish the position of the minor axis of the Cygnus source. These measurements showed the axis to lie in position angle 007°.

(iv) *Polarization measurements and low frequency spectrum.*—The work on the polarization of the Cassiopeia, Cygnus and Taurus sources (6) and on the low frequency spectrum of Cassiopeia and Cygnus (7) referred to in the last report has now been published.

Drift movements in the F region of the ionosphere.—Observations with the 79 Mc/s receiving equipment which is beamed continuously on the radio source Cassiopeia A have been continued practically without a break. The results of an analysis of the observed temporal variations in amplitude and periodicity of the radio flux from the source are in publication (8). During this analysis it was noticed that unusually large amplitude fading sometimes occurred having a different character from normal fading and lasting over periods of about 30 minutes. Most of these " ridges " occurred in the months of June and July and appeared to correlate with high E region critical frequencies rather than with any F region phenomenon. The details of this work together with suggestions as to the mode of production of the ridges is in publication (9).

The triangularly spaced 3 station equipment, using a base line of 1000 m, has been used to obtain more data on the apparent reversal in the direction of

drifts within the F region which is sometimes observed. The results obtained are insufficient to be conclusive but it appears that a reversal is most probable when the degree of magnetic disturbance is high (10). During the summer months an attempt was made to use the equipment to measure the velocities associated with the formation of a ridge. Few ridges were observed in 1956, but the results supported the suggestion that ridges are not caused by an F region phenomenon but by unusually large electron densities in the E region.

A record of the observations made with both the continuously following and spaced receiver equipments following the solar flare of 1956 February 23 have been published (17) along with data from the auroral radio echo and geomagnetic field equipment at Jodrell Bank. A discussion of the scintillations observed at the time of the solar eclipse of 1954 June 30 has also been published (11).

The 21 cm line of interstellar neutral hydrogen.—A detailed account (12) has been published of absorption measurements at 21 cm on the four major sources. A distance was estimated from the absorption spectrum of each source. The 30 ft paraboloid and double comparison spectrometer have since been used to derive the absorption spectrum of Cygnus X, the extended radio source lying at Dec. $=40°$ and R.A. $=20^h25^m$ (13). Absorption was found at the frequency of the first and second spiral arms in this direction. Moreover, the magnitude of the apparent absorption in the second spiral arm followed the contours of Cygnus X and amounted to twice the brightness temperature of the source. These observations could only be explained by a deficiency of neutral hydrogen in the position of Cygnus X. An analysis of the continuum radiation from the source indicates that it is an H II region and it is therefore suggested that a substantial fraction of the neutral hydrogen in the second spiral arm (at about 6 kiloparsecs) has been ionized to form the Cygnus X source.

The original absorption measurements on Saggitarius A (14) indicated that it was situated between the Sun and the galactic centre. A further analysis (15) has been made of the published observations of continuum emission in this direction. This shows that the observations at all frequencies can be understood in terms of an H II region lying in front of the extended background components of emission.

Clear evidence has been found for the variation in the kinetic temperature of interstellar neutral hydrogen (16). In the direction of dense dust clouds in the Milky Way, the brightness temperature of neutral hydrogen emission falls considerably below that in nearby regions. The observations can be interpreted in terms of a model cloud containing a concentration of the normal interstellar constituents. Such a cloud is expected to be cooler when its density is higher, due to the increased cooling action of molecular hydrogen. A cloud in Auriga was found to consist of 200 solar masses of neutral hydrogen with one solar mass of dust. In some clouds in Cygnus the kinetic temperature was as low as 25 deg K compared with the mean interstellar temperature of 125 deg K.

Aurorae.—Full-time radio echo observations of the aurora borealis were continued in 1956 using the rotating aerial equipment. Echoes were detected on 14 days during the year compared with 4 days during 1955. This increase in the number of aurorae detected was expected in view of the approach of the sunspot maximum. A large amount of auroral activity during the spring months

promised a year of unusually high activity. This, however, did not materialize, the summer months being singularly lacking in aurorae. The autumn months, however, brought a return of activity and for 1956 as a whole the aurorae were concentrated in the months near the equinoxes.

Two aurorae were of particular interest. The unusual solar flare of 1956 February 23 was followed by a geomagnetic storm on February 25. During the storm auroral radio echoes were detected from 1537 to 2022 U.T. The echoes were found to be in no way different from those normally obtained in the afternoon (**17**). No visual aurora was observed when darkness fell even though all observers had been alerted.

The other aurora occurred on September 8. Echoes were detected for a period of less than one hour during the afternoon and for the most part were very intense. At this time the aurora australis was observed visually from the low geomagnetic latitudes of 37° and 43°. After darkness the aurora borealis was observed visually in the British Isles but not below geomagnetic latitude 59°N. No radio echoes were detected at that time (**18**).

Measurements of the geomagnetic field.—For some years measurements of the terrestrial magnetic fields have been made at Jodrell Bank using a fluxgate magnetometer. A brief description of the original instrument has been given by Maxwell (**19**). The magnetometer was used to record variations in the east-west component of the field until mid-1956. At this time two similar instruments were brought into operation to replace the old magnetometer, and these have since been used to record continuously the variations of the north (H) and vertical (V) components. An account of the new instruments is given by Watkins (**20**). The sensitivity is such that changes of 10γ ($1\gamma = 10^{-5}$ gauss) in the H or V component are detectable.

The magnetometers are most reliable in indicating a build up of geomagnetic and ionospheric disturbances. These often result in the detection of auroral radio echoes and in fast fluctuations in the intensity of radio stars. Thus auroral activity can be expected some hours before it is actually detected. This is illustrated particularly well by the geomagnetic storm of 1956 February 25. The storm started with a sudden commencement (S.C.) at approximately 0300 U.T., whereas auroral radio echoes were not obtained until 1537 U.T. the same day. It has also been shown that the occurrence of auroral radio echoes and fast radio star fluctuations correlate with individual features on the magnetic records (**21, 22**).

Meteor orbits and meteor survey.—The details of the 3 station technique for the measurement of individual meteor orbits have now been published (**23**).

Following the work on sporadic meteors of magnitude +7 and +8 (**24**), which was referred to in the previous report, a further survey has been made during 1956 of brighter meteors, magnitude about +5. The analysis of this survey is in progress. Observations have also been made on a number of showers, including the December Ursids in 1954, from which six orbits were measured, giving the following mean values: $a=7\cdot7$, $e=0\cdot88$, $i=51°$, $\omega=206°$, $\Omega=271°$. These agree well with the orbit of comet Tuttle. The η Aquarid and Orionid streams have been investigated, but the analysis is not complete. No sign of the Giacobinid stream was found in 1956.

The continuous meteor survey equipment has been in operation throughout the year and observations on all the major meteor streams were successfully

made. Some of the data have been published in a note on the interpretation of transient echoes from the ionosphere (**25**). An analysis of the survey of sporadic meteor radiants made during 1949–1951 has now been published (**26**).

Meteor physics.—A radio echo equipment operating on a frequency of 36 Mc/s has been designed specifically for the purpose of meteor height finding and is now under construction. It is intended to use the data obtained to find the atmospheric scale height and density in the height range 85–105 km, and to investigate the diurnal and seasonal variations of these quantities throughout the I.G.Y.

The equipment will also be used together with the existing 68 Mc/s equipment, and in conjunction with a remote meteor camera to find the relation between the ionizing and luminous efficiencies of evaporating meteor atoms and the velocity dependence of these quantities.

The phase changes in the radio echoes from meteor trails, associated with plasma resonance effects, have been investigated using a coherent pulse phase measuring technique (**27**). As the ionized columns diffuse the axial electron line density falls, and resonance occurs when the dielectric constant at the centre of a trail passes through the value $K=-1\cdot4$. The enhancement in echo amplitude due to resonance, when the electric vector in the incident radio wave is perpendicular to the trail, has been investigated both theoretically and experimentally (**28, 29**). In addition to the increase in amplitude, the phase of the radio echo also undergoes a reversal of 180°. For a trail with a gaussian distribution of electron density, 135° of this phase change should occur before resonance, and 45° after resonance (**30**). Rapid changes in phase of this type have been found experimentally, agreeing in both magnitude, direction and duration with theory. Observations were made at a frequency of 36·3 Mc/s, transmitter pulse 50 kw and pulse length 30 μs.

The work on the mass distribution of shower and sporadic meteors referred to in the last report has now been published (**31**).

Meteor photography.—The operational programme of the Meniscus Schmidt camera was continued through 1956. Efforts made to photograph sporadic meteors, however, met with little success. During the first six months of the year four meteors were photographed, one of which yielded a correlation with a radio echo. The three major photographic meteor showers, Quadrantids, Perseids and Geminids were almost completely blotted out by bad weather. Three Geminids were photographed through a temporary break in the cloud but did not yield correlated radio echoes as they were observed in the zenith.

A critical analysis of sensitivity was made during the summer months and the conclusion reached was that the atmospheric absorption over Jodrell Bank gave rise to the extremely low photographic rate. The number of clear nights, free of moonlight, averages about three per month and the average atmospheric, visual, zenithal absorption on three nights is about 1 magnitude. The effective photographic absorption in the field of view of the camera thus averages more than two magnitudes, since the camera is necessarily directed at an elevation of 45° to cover the same field as the associated radio echo equipment.

A new site for the camera was obviously desirable, with as clear an atmosphere as possible, a high incidence of clear nights, where it would be possible to observe in the zenith with the camera, and at the same time cover the same volume of the atmosphere in the meteor region as the radio echo equipment

sited at Jodrell Bank. Such a site has been obtained in the Lleyn Peninsula of North Wales. In view of the completion at Bristol University of the main model Schmidt camera early in the new year it has been decided to install this at the new site.

The camera should be operating by mid-February when a comprehensive combined radio echo photographic programme will be initiated. The pilot model camera is to remain at Jodrell Bank and will be used during the major showers in conjunction with the combined programme.

E region winds.—Systematic wind measurements in the 80 to 100 km height region, using radio echoes from drifting meteor trails, have continued during 1956 (**32**). Diurnal and seasonal variations of the wind are investigated, and of particular interest is the semi-diurnal wind component due to tidal oscillations of the Earth's atmosphere. Large phase variations in this component are observed, particularly in the autumn months, and these phase variations have repeated each year. Similar seasonal variations in the prevailing wind have also been recorded in all three years—namely wind components towards the east in the summer and winter, and towards the west in the spring and autumn.

The structure of turbulence in the 80–100 km region has been investigated by the simultaneous measurement of wind velocities at two points along a meteor trail. The fall-off in correlation between the wind velocities at the two points, as their separation is increased, has been used to obtain a measure of the eddy size. The turbulence is found to be anisotropic, the vertical scale being approximately seven kilometres, while the horizontal extent is appreciably larger. The R.M.S. turbulent velocity of 25 m $\sec^{-1}$ is of the same order as the uniform wind components. A mean turbulent wind stream of 10 m $\sec^{-1}$ km^{-1} is found, with occasional values of up to 100 m $\sec^{-1}$ km^{-1}.

Lunar echo work.—The investigation of the slow and fast period fading of the lunar radio echoes referred to in the last report has now been published (**33**).

In the year under review the lunar echo equipment has been used to study the slow fading of the echoes, which is caused by the rotation of the plane of polarization of the radio wave due to the magneto-ionic effect in the earth's ionosphere. The number of rotations ω depends upon the electron density N and the frequency of the radio wave f. It has been shown on the basis of the most likely distribution of electrons between the earth and the moon that $\sim$98 per cent of the rotation will occur in the ionosphere, and thus by measuring ω we have a direct means of measuring the total electron content of the ionosphere. The technique developed has been to observe the slow fading on two frequencies separated by 1·2 per cent (switching the equipment alternately between the two frequencies every 3/4 minute). Observations on either frequency alone yield only $d\omega/dt$. However, observations on two frequencies give two curves which are similar but displaced in time. If the time separation δt is measured at any time then the angular separation between the two planes of polarization of the two frequencies is known, and the total ionospheric electron content can be determined.

Observations have so far been made during nine lunar months, and some preliminary results have been published (**34**). Unfortunately most of the lunations have been disappointing in that there has been little day to day continuity in the fading. As a result it is unlikely that these lunations will yield accurate results. Where reliable results have been obtained, it has been found

that the ionospheric electron content observed is about twice that expected in a parabolic layer based on Slough $p'f$ data. Thus it would appear that on these occasions there were about three times as many electrons above the level of the maximum than below. It is hoped that during 1957 the present transit aerial will be replaced by a fully steerable instrument, with which it is expected that more comprehensive measurements will be made.

Optical interferometer.—Following a preliminary experiment (**35**) on the correlation between the times of arrival of photons in coherent beams of light, a second laboratory experiment has been carried out under more precisely controlled conditions. The results (**36**) show satisfactory quantitative agreement with theory. In reply to criticisms, based on the results of experiments carried out with coincidence counters, a brief theoretical outline of the results to be expected with counters has been published (**37**).

A stellar interferometer has been constructed solely for the purpose of testing the technique. This instrument uses two photo-multipliers mounted in Army searchlight mirrors of 156 cm diameter. Measurements (**38**) were made of the apparent angular diameter of Sirius A. The experimental result, $0{\cdot}0068'' \pm 0{\cdot}0005''$, is consistent with the value predicted from the bolometric magnitude and temperature. The operation of this preliminary instrument appeared to be substantially independent of atmospheric scintillation and it is believed than an instrument of this type could readily be made to yield an extremely high resolving power.

The design of a second interferometer, based on the same principles, is under consideration. It should be possible to make an instrument capable of measuring the angular size of many stars, and in particular it is intended to measure very hot stars of early spectral type.

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University Observatory, Oxford

(*Director, Professor H. H. Plaskett, F.R.S.*)

Apparatus and equipment.—The mechanical parts for the large spectroscope were received in the latter half of the year. The flexo-metal tube enclosing the optical path has been completed, modifications have been made to the cover over the optical parts and the temperature control for the tunnel installed. It is hoped that the spectroscope will be ready for use in the observing season of 1957.

Two of the offices in the original part of the building have been converted into a spectroscopic laboratory. This loss of office accommodation has been more than compensated by the conversion of the old lecture room into four offices, a workshop and a small, convenient lecture room.

Solar work.—Dr Adam has measured red shifts for strong solar lines in the interferometric spectra obtained by her in the 1955 observing season. These measures, combined with those obtained in her earlier investigations, show a correlation between red shift and equivalent width, though with a different slope for the regression line from that given by the red-shift measures of Allegheny and the Bureau of Standards.

A theoretical investigation of the excitation of the chromosphere (4) has suggested that some part of the dependence of red shift on line strength may be a chromospheric phenomenon (see *The Observatory*, **76**, 217, 1956). In addition to their possible use in the interpretation of red shifts, chromospheric observations are essential in finding the physical conditions in the transition zone between the photosphere and the corona. For these reasons the observing programme for 1956 was devoted to the chromosphere. With the 35·2 m telescope Dr Treanor made further observations (6), with an interferometer crossed with a low dispersion spectroscope, of chromospheric Hα and D_3. He then used the spectroscope alone to study the latitude dependence of He I λ10124, following the similar investigation by Mr Bishop (1) of this dependence for Hα and D_3. With the 19·8 m telescope and its associated high dispersion spectroscope, the height dependence of the H and K lines was investigated by the Director and of the companion Ca II lines at $\lambda\lambda$8498, 8542 and 8662 by Dr Treanor.

From microphotometric measures of the velocities of the Na D lines, Dr Hart (3) has been able to show that the amplitude of the velocity field,

found in her earlier work, diminishes rapidly with height in the photosphere. Profiles of these lines, fully corrected for the effect of the apparatus function, have been found by Dr Bray (2).

Galactic rotation.—Combining his measured radial velocities of the southern Cepheids with those of Joy for the northern Cepheids, Dr Stibbs (5) has made a solution for solar motion, galactic rotation and a K term. The value of the Oort constant is found to be $19{\cdot}5 \pm 1{\cdot}9$ km sec^{-1} kpc^{-1}. The rotation of the Cepheid system as a function of the distance from the galactic centre has been investigated by Camm's method, and a comparison is given between the rotation function $f(R, R_0)$ found from the Cepheids and that from the Leiden 21 cm data.

Laboratory investigations.—As already noted a spectroscopic laboratory has been built and equipped during the year. Dr Hindmarsh has commenced a series of investigations on the validity of the pressure shift of spectrum lines predicted by Lindholm.

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University Observatory, St Andrews

(*Director, Professor E. Finlay-Freundlich*)

Staff.—Miss J. Lawson joined the Observatory as Secretary.

The research students Mr A. MacAulay and Mr J. W. Wilson left the Observatory after their respective research periods ; Mr P. Byard joined the staff as a research student.

Scientific Research

(*a*) Workshop report (Mr R. Waland). The 8-inch aperture refractor, which will serve as a guiding telescope for the 37-inch Schmidt–Cassegrain, has been completed. The objective is of the coma-free form.

The lower end of the 37-inch Schmidt–Cassegrain containing the primary and secondary mirrors has been completed.

A temporary upper tube is being constructed to enable the Schmidt plate to be tested optically in conjunction with the mirror system. Preparation for the optical working of the Schmidt plate aspheric surface is almost complete. When the exact distance of the Schmidt plate from the mirror system is known the construction of the upper tube will commence. The flotation system for the inner defining tube carrying the Schmidt plate is under construction.

(*b*) Auroral station (Dr Jarrett). At the auroral station in connection with the forthcoming International Geophysical Year, Dr A. H. Jarrett and Mr P. Baylis have continued construction of the radio echo equipment for auroral research. Mr P. Byard has taken over research with the $f/0{\cdot}7$ auroral spectrograph.

An all-sky camera for recording of aurorae has been received from Upsala Ionospheric Observatory and is being mounted and tested.

(*c*) Dr J. Cisar continued his investigation of the distribution of cluster variables and is experimenting with a new method of their detection. Experimental results obtained in the application of a Fabry–Perot interferometer to the measurement of turbulence in gaseous nebulae proved so inconclusive that the experiment has been temporarily abandoned, to be resumed with the large 37-inch telescope when the latter is completed.

(*d*) Miss B. Middlehurst resumed in September her photometric work with the 20″ Schmidt–Cassegrain.

(*e*) Mr E. Forbes and Professor E. Finlay-Freundlich have continued research on the red shift of the solar lines.

Norman Lockyer Observatory of the University of Exeter

(*Superintendent, Mr D. R. Barber*)

The Observatory suffered a severe loss by the death on 1956 September 23 of Mr D. L. Edwards, the Director since 1936. An appreciation of his life and work appears on p. 252.

Work has continued on three routine programmes of research, namely, relative gradients of early-type stars ; the spectrum and colour temperature of γ Cassiopeiae ; and the spectrophotometry of the twilight Na airglow.

In connection with the last-named programme, the large Littrow spectrograph has been prepared for use in order to obtain, simultaneously, high-dispersion spectra of the sodium D-lines from different regions of the day sky ; and five photographs were obtained at twilight with the twin-lens, twin-mirror camera (described in the last report) to test a method of demonstrating the twilight Na emission–absorption pattern by means of composite positive–negative photographic enlargements.

The first of a short series of papers summarizing the results of photoelectric twilight observations of the Na D-band, obtained with the polarization photometer during 1949–51, is now in the press.

Dunsink Observatory

(*Director, Professor H. A. Brück*)

Staff.—Dr G. I. Thompson resigned his post as Assistant at the end of September to join the staff of the Cambridge Observatories. Mr B. G. Tunmore resigned his Scholarship at the end of June.

Instruments.—The equipment for solar work has been improved in several ways : the mechanism of the oscillating slits in the spectrohelioscope has been redesigned, and the performance of the same instrument has been further improved by the acquisition of a 3-inch blazed Bausch and Lomb grating.

In connection with the proposed flare patrol, an Atmospherics Receiver with an Evershed Recorder has been obtained for the registration of Sudden Enhancements of Atmospherics (S.E.A's).

A Cambridge Ratio Recorder has been acquired for photoelectric photometry in the solar spectrum and in particular of the H- and K-lines.

The Decatron registers of the pulse-counting photometer mentioned in last year's Report have been increased to three ; with this arrangement counts in three-colour-photometry or similar spectrophotometric work can be " interlaced ". Tests of the performance of the photometer have been carried out by Dr Smyth in the laboratory.

Through the kindness of Professor S. Devons and Dr J. Ring of the Physical Laboratories of the University of Manchester, Dr Smyth was enabled to spend a fortnight at Manchester and make there with Dr Ring's apparatus a graduated 17 layer interference filter ; the transmission of this filter varies between 4200 A and 4600 A along a distance of 10 cm, with a half-width of the transmission band of 20 A and a transmission of 60 per cent.

Solar work.—Dr Thompson's work on the photometry of the ultra-violet solar spectrum has continued. The region down to 3200 A is now sufficiently well covered by satisfactory spectrograms. The remaining region down to the ultra-violet limit is to be dealt with in the spring of 1957.

Intensity records have been obtained of part of the available material by Dr Thompson who has also made an attempt at a theoretical analysis. It is expected that the whole photometry, now in the hands of Dr M. T. Brück, will be complete by the summer of 1957.

Systematic observations of solar activity were started by Dr M. T. Brück in August and continued until November. Arrangements have been made for the Observatory to take part in the flare patrol during the International Geophysical Year.

Stellar work.—Dr Smyth secured a set of photoelectric observations of 12 Lacertae as part of Dr de Jager's co-operational programme.

Following earlier experiments by Dr H. E. Butler, Dr Smyth also made some tests on the simultaneous photometry of 2 stars with photoelectric photometers ; these were attached to the 28-inch reflector and the 12-inch refractor. No significant results have been obtained so far.

Dr Smyth made preparations for using the 28-inch telescope for a spectrophotometric programme on the intensity of the 4430 A interstellar band in early-type stars, using the interference filter mentioned earlier in front of the photoelectric photometer.

ADH-Telescope and Boyden Observatory.—Professor Brück attended a meeting at Bonn of the Administrative Council of the Boyden Observatory. Lack of staff has made it impossible, unfortunately, to send this year an observer from Dunsink to South Africa or to make progress with the measurement of the existing cluster plates.

Dominion Observatory, Ottawa

(Director, Dr C. S. Beals)

Positional Astronomy.—The time service of Canada was maintained as usual, based on nightly observations with the Photographic Zenith Telescope and on the use of five crystal clocks. The P.Z.T. was also utilized for observations of the variation of latitude. Time signals accompanied by a voice announcement each minute were broadcast continuously on frequencies 3330, 7335 and 14670 kc/s.

The meridian circle was in continuous use and 6200 observations for star positions were made. The project for a mirror transit made satisfactory progress, the main optical and mechanical parts being delivered during the year. A building has been designed and construction is expected to begin in 1957.

Stellar Physics.—Routine observations of solar flares with a Lyot filter were begun during the year in preparation for intensive observations during the

Geophysical Year. Solar spectroscopic work included photographic studies in the infra-red of line displacements in the centre and limb of the Sun and photo-conductive studies of molecular spectra in the region of sunspots.

At the meteor observatories at Meanook and Newbrook, Alberta, about thirty pairs of photographs suitable for orbital and deceleration studies have been secured. Eleven meteor spectrographs were operated and eight usable spectra were observed. A profile study of the new Quebec Crater was published while drilling operations were carried on at the crater at Holleford, Ont. In both cases the results were favourable to the meteoric hypothesis. At Holleford explosion breccia and powdered rock were found at depths up to 1125 ft indicating similarity to the well-confirmed Barringer Crater in Arizona.

Geomagnetism.—Magnetic observatories were maintained at Agincourt, Ont., Meanook, Alta., Baker Lake and Resolute Bay, N.W.T. Earth current observations were started at Meanook, while buildings were erected at Yellowknife, N.W.T. and Victoria, B.C. for magnetic and auroral observations during the Geophysical Year. An astatic magnetometer was constructed at Ottawa for rock magnetism studies. Ten three-component electronic recording variometers were designed and constructed for use at magnetic auroral and ionospheric stations during the Geophysical Year. Magnetic field operations continued as well as the construction and revision of magnetic charts. Ten papers were published dealing with various aspects of geomagnetism.

Gravity.—Precise gravity ties were made during the year between Ottawa and Washington as well as between Ottawa and Geneva, Switzerland. Gravity observations were used to delineate the boundaries and to estimate the depth of fossil meteoritic craters at Holleford and Franktown, Ont. A combined gravity and geological study of Deep Bay, Sask., indicated that it is probably a meteorite crater with a rim diameter of approximately 8 miles. Gravity mapping progressed at an accelerated rate and regional data is now available for approximately half the country.

Seismology.—The permanent Canadian network of 10 seismograph stations was maintained and experimental stations were operated at Banff and Knob Lake. Field refraction studies were made at the Holleford crater and assistance was given in studies of rockbursts in mines at Springhill, N.S. and Fernie, B.C. Studies of the direction of motion in the fault planes of earthquakes were continued, bringing up to 65 the number of earthquakes for which solutions have been made. A bridge has been developed for the calibration of electromagnetic seismographs and the eastern Canadian seismographs have been calibrated on a uniform system.

David Dunlap Observatory, University of Toronto

(*Director, Professor J. F. Heard*)

Radial velocities.—Velocity determinations have been completed for a group of 60 stars for testing their membership in the Alpha Persei Cluster. Observations have been completed for two lists of stars in extensions of certain of the Kapteyn areas. Further observations have been made of groups of faint OB stars and stars in the galactic polar cap.

Miss Northcott has completed orbits for the double-line spectrographic binaries HD 15138 and HD 82780 and has obtained velocity curves for

HD 154528, HD 214946 and HD 36484. Wellmann completed spectrographic orbit solutions for HD 153345 and BM Cas, both eclipsing variables. Heard has obtained velocity observations of SZ Psc and RW Mon for orbit determinations.

Extensive series of spectrograms of θ Oph were obtained for Van Hoof of Louvain who has confirmed the short-period velocity variations of this star; also the Observatory co-operated in the intensive programme of observations of 12 Lac which was organized by de Jager of Utrecht.

Photometry.—Bakos made photoelectric observations of a selected group of visual binaries and of 12 Lac, HD 200391 (a new eclipsing variable) and HD 30353.

Stellar spectra.—Wellmann completed a study of the eclipsing system, 32 Cygni, based on spectrograms of the 1949 and 1952 eclipses taken at the Michigan, Hamburg and David Dunlap Observatories.

Stellar luminosities.—Oke has extended his method of obtaining precise luminosities from microphotometer tracings. He has applied this successfully to groups of stars of spectral classes F5 to K1.

Computation.—The method of solving spectrographic binary orbits by electronic computer which was developed by MacRae has been systematized to the point where the Observatory can undertake such solutions for observers elsewhere.

Wellmann developed a method of making solutions for eclipsing variables using an electronic computer. In this manner he made a new solution for the photometric orbit of AK Her from photoelectric observations by Bakos.

MacRae in collaboration with Westerhout of Leiden has computed a set of tables for the reduction of 21-cm velocity observations to the local standard of rest. These have been published by the Lund Observatory.

Searle has continued a theoretical investigation of the hydrogen recombination spectra. A preliminary analysis involving six and seven principal quantum levels and the continuum and including the effects of fine structure has indicated the need to extend the computations to a more complete model. To this end transition probabilities for the higher transitions have been computed.

Radio astronomy.—During 1956, in collaboration with the Department of Electrical Engineering at the University of Toronto, the Observatory entered the field of radio astronomy. A small laboratory housing receivers has been built at the Observatory, an array of zig-zag elements on an equatorial mounting has been constructed and a large electromagnetic horn is being designed. This equipment will be used on 300 Mc/sec for electromagnetic flux measurements and for a solar patrol during the International Geophysical Year. MacRae is in charge of this project.

Instruments.—A photoelectric spectrophotometer designed by Oke and MacRae and constructed in the Observatory workshop has been bench-tested. It is intended for use with the 74-inch telescope in the study of stellar spectra.

Oke has converted the Observatory's microphotometer into a direct-intensity recorder using a commercially-available electronic instrument which is a combined x–y plotter and data-correcting device.

Bibliography.—Mrs Hogg has made a card catalogue of the literature on galactic clusters, supplementing the catalogue which she has maintained for globular clusters. Indexes of this will be published in the course of time.

Staff.—The Observatory suffered the loss of its founder by the death of Dr C. A. Chant, Director Emeritus, on 1956 November 18.

Dr J. B. Oke was promoted to the rank of Assistant Professor. Dr Helen Hogg was on leave of absence for part of the year as Programme Director for Astronomy at the National Science Foundation in Washington. Dr Peter Wellmann who had been Visiting Lecturer returned to Hamburg Observatory. Dr Leonard Searle has been appointed Lecturer.

Publications.—Since the last report, *Pub. D.D.O.*, Vol. **2**, No. 4 has been issued.

Dominion Astrophysical Observatory, Victoria

(*Dr R. M. Petrie, Dominion Astrophysicist*)

Staff.—Miss A. B. Underhill rejoined the staff in June after spending an academic year at the Harvard College Observatory. Miss J. K. McDonald went on leave of absence in September to spend the academic year in the Department of Astronomy, University of California. W. G. Milne, of the seismological section, remained on leave at the University of California. Mr J. R. White joined the staff as instrument maker in May. Mrs D. M. Sewell, Secretary of the Observatory for eight years, resigned in October and was replaced by Miss T. C. Thompson. E. H. Richardson, assistant in astronomy, resigned in 1956 May to continue graduate study and was replaced by J. D. Francis. Dr R. S. Kushwaha, Post-Doctoral Fellow of the National Research Council, took up residence at the Observatory on September 1.

R. M. Petrie attended the " Cosmic Scale Conference " at the University of Virginia in April and A. McKellar attended the Seventh Liége Astrophysical Symposium in July. Invited papers were presented at these meetings.

The following held temporary staff appointments during the year: Professor W. W. Morgan, Yerkes Observatory; E. Butkov, University of British Columbia; J. L. Climenhaga, Victoria College; A. K. Goodacre, University of British Columbia; and S. C. Morris, Victoria College.

Spectroscopy.—As in the past few years, a substantial effort has been made to obtain knowledge of long-period eclipsing binaries of the ζ Aurigae class. High-dispersion grating spectrograms, covering a wide range in wave-length, have been obtained of the systems ζ Aurigae, ϵ Aurigae, VV Cephei. Some of the exposures were of two, and three, nights duration.

A. McKellar and K. O. Wright have found numerous double lines in the chromospheric eclipse spectra of VV Cephei. The relative positions and intensities of the components varied during the weeks preceding geometrical eclipse. Spectroscopic data suggest that first contact took place about the end of June and total eclipse began about a month later.

Preliminary results from recent spectra of ϵ Aurigae have been obtained by Wright. Hα exhibited large variations during totality; the emission and absorption components reversed themselves about a central emission during totality, but did not do so symmetrically.

High dispersion spectra of 31 Cygni obtained at the 1951 eclipse have now been analysed in detail by Wright. Curve-of-growth analysis of intensities

of iron lines yield turbulent velocities varying from 7 km/sec to 12 km/sec. Excitation temperatures varied from 5200 deg at 15 days before total eclipse began to 2900 deg at 2 days before total eclipse. There is some evidence of abrupt changes with phase in the deduced excitation temperatures. The number of iron atoms producing the observed lines increased by a factor of 10^4 during the interval mentioned above.

Extensive observations of certain β Cephei stars have been secured by G. J. Odgers. Some 300 spectrograms (2-prism dispersion) of 12 Lacertae were obtained during the international cooperative programme August 28 to September 12. Observations were made on 11 nights covering 14 cycles of the stellar variation, and several cycles were covered at other times with spectra giving the Hα region. Observations with two- and three-prism spectrographs have been made on β Cephei and γ Eridani, at Hα and in the photographic region.

Radial velocity measures have been completed on the 1955 and 1956 series on BW Vulpeculae and on the 1955 series on γ Pegasi. Photometric measures of Hα are proceeding on spectrograms of β Cephei.

Miss A. B. Underhill has resumed study of O-type spectra, measuring the positions of all features visible on moderately high-dispersion spectra covering the range $\lambda\lambda$ 3200–6700. Several hundred lines have been measured including a great many features of marginal appearance and intensity. Spectra originating in 22 atoms and ions appear to be present. Spectrophotometric measures of the more prominent lines are going forward.

Double lines observed in spectra of ρ Cassiopeiae have been studied by McKellar in collaboration with Dr W. P. Bidelman of the Lick Observatory. The material has been taken from high-dispersion spectra obtained in the years 1951 to 1956.

The measurement of spectral line intensities in spectra of class B is being continued by Miss J. K. McDonald and E. K. Lee. Single-prism spectra are analysed, the principal features appearing in these spectra being measured for total absorption. The list of lines includes Hγ and the interstellar K line. To date about 200 spectra have been analysed and line intensities are measured in about 100 early B spectra.

Stellar Motions.—Some 1800 spectrograms have been measured for radial velocity during the year. The spectra are largely those of B stars, β Cephei stars, stars in the north galactic pole cap, members of stellar associations, and spectroscopic binaries. The greater part of this work has been carried out by Odgers, Pearce, and Petrie.

Progress was made in the measurement of radial velocities of faint B stars. To date Petrie has determined the radial velocities of 240 B stars and Pearce has measured 120. A few spectrograms remain to be taken to complete the programme, which embraces about 550 stars of spectral type B5 and earlier, north of declination $+20°$, and between apparent magnitudes 7·5 and 8·6.

Wave-length standards for radial velocity work with low dispersion are being determined by Petrie with the assistance of D. H. Andrews and Miss McDonald. Some 225 spectrograms of standard stars in the range B0 to K5 have been measured and a preliminary list of suitable lines has been selected. The wave-lengths finally adopted will yield velocities on the system previously set up with the higher dispersions. The instrument used is a single-prism

spectrograph giving a linear dispersion, at $H\gamma$, of 92 A/mm which will allow of the extension of our radial velocity work to stars of apparent magnitude 10 or even 11.

Petrie and Andrews have revised the calculations of Oort's constant A taking account of regression error. Radial velocities of 79 B stars were employed as well as 64 interstellar values. The numerical results by Weaver's method agree with those from the usual "double-wave" formula. A value of $A = 17 \cdot 7 \pm 1 \cdot 1$ km/sec/kpc is found.

Binary Stars.—Miss Underhill has continued radial velocity measurements of visual binaries of short period. The systems 10 Ursae Majoris, β Leo Minoris, and 85 Pegasi, show clearly-defined velocity changes. Results for ζ Herculis, ϵ Hydrae, ADS 9247 BC, β Delphini, and α Ursae Majoris, are less definitive and indicate departures from the expected velocity curves. The work is being continued.

Pearce has found four spectroscopic binaries among the members of the Pleiades, thus requiring revision of the opinion that spectroscopic binaries were lacking in this galactic cluster. The stars now found to vary in radial velocity are the following A-type members: HD 22637, HD 22805, HD 23904, and HD 24769. Pearce has also determined orbital elements for the spectroscopic binary HD 24118.

Revised orbital elements have been determined for δ' Lyrae by McKellar and Richardson and for α Draconis by Pearce. Argyle has observed the B-type binary HD 175544 with the photoelectric photometer and concludes that the system does not undergo eclipses.

On August 16–18 a conference on Binary Stars, sponsored by the National Science Foundation (U.S.A.), was held at the Observatory. In addition to the local staff, eighteen astronomers attended from the United States and Canada. Sessions were devoted to observational problems in double star astronomy and to problems of the origin and evolution of double stars. The proceedings of the Conference will appear in an early issue of the *Journal of the Astronomical Society of Canada.*

Photoelectric Observations.—The photoelectric photometer was used by Argyle on seven nights. Magnitudes and colours were measured of 75 stars in the North Galactic Pole Cap.

Theoretical studies.—G. J. Odgers and R. S. Kushwaha have commenced studying the passage of shock waves in stellar atmospheres with special reference to β Cephei stars. Preliminary results indicate that the theory will give a general accordance with the radial motions measured in the atmospheric layers of BW Vulpeculae.

Miss Underhill has computed four model atmospheres corresponding to early B stars and derived theoretical line profiles for lines of Si^{+}, Si^{++}, and Si^{+++}. Comparison is made with line profiles measured in spectra of 10 B-type stars. The model with $T_0 = 16\,800$ deg corresponds to type B 2·5, main sequence, while that with $T_0 = 18\,800$ deg corresponds to B 1. It is concluded that strong lines are formed largely in the chromospheric layers, outside the region covered by the models.

Seismology.—Five western Canada stations were maintained and records were inspected and read. A new station at Banff, Alta., was brought into the network. New long-period galvanometers have been installed at Horseshoe Bay for the better recording of teleseisms.

Experimental work with submarine explosions was carried out with the co-operation of the Royal Canadian Navy and the Pacific Naval Laboratory. The data obtained are being analysed to supply the speed of seismic waves in this locality.

A study of disturbances and shocks in the coal mining areas of western Alberta and eastern British Columbia has been completed and prepared for publication.

229 local earthquakes were recorded up to December 15.

Instrumentation.—Progress has been made toward the acquisition of a new telescope: a proposed 48-inch reflector for photometric work and coudé spectroscopy. A design for the mounting has been worked out and specifications for the optics and mounting have been prepared. A one-tenth scale model of the proposed telescope has been constructed in the shop.

A device for automatic guiding at the stellar spectrograph has been designed by P. E. Argyle and A. R. Salonen. The electronic section has been built and the mechanical parts are under construction.

During the year an ultraviolet spectrograph, using quartz optics, was put into commission. The instrument photographs stellar spectra to the limit of atmospheric transmission with a linear dispersion of 40 A/mm at λ3400.

D. H. Andrews and J. R. White have designed and built new mountings and illumination systems for the plate measuring machines. The change has resulted in increased efficiency and lowered fatigue in measuring stellar spectrograms.

Publications.—The following papers were submitted for publication:

Publications of the Dominion Astrophysical Observatory

Vol. X, No. 13. " Tests of the Victoria Absolute Magnitude of Stars of Class B, and spectroscopic Absolute Magnitudes of 184 Stars " by R. M. Petrie and B. N. Moyls.

Vol. X, No. 14. " The Stellar Photometer of the Dominion Astrophysical Observatory " by P. E. Argyle.

Vol. X, No. 15, " The Integrating Exposure Meter of the Dominion Astro-Physical Observatory " by J. B. Warren and P. E. Argyle.

Vol. X, No. 16. " The Spectrographic Orbit of HD 123299, Alpha Draconis " by J. A. Pearce.

Vol. X, No. 17. " Spectrographic Observations at the 1953 and 1955–56 Eclipses of Zeta Aurigae " by A. McKellar and E. Butkov.

Vol. X, No. 18. " The Spectrographic Orbit of HD 24118 " by Joseph A. Pearce.

Contributions of the Dominion Astrophysical Laboratory

No. 47. " Symposium on Non-Stable Stars ", " The Chromospheric Spectrum and the Atmosphere of 31 Cygni " by A. McKellar and R. M. Petrie.

No. 48. " Values of Oort's Constant *A* Derived from B Stars " by R. M. Petrie, P. M. Cuttle and D. H. Andrews.

No. 49. " The Chromospheric Spectrum of VV Cephei in April and May 1956 " by K. O. Wright and A. McKellar.

No. 50. "Identification of the λ 10460 Sequence of Bands in Late M-Type Spectra with Vanadium Oxide" by A. McKellar.

No. 51. "Molecules in the Solar System" by A. McKellar.

No. 52. "Evidence for Turbulent Motions in Stellar Atmospheres" by K. O. Wright.

Union Observatory, Johannesburg

(*Director, Dr W. H. van den Bos, Union Astronomer*)

The 26½-inch refractor has been used on 135 nights with the interferometer by Dr Finsen for the measurement of known double stars and a survey for new ones, on 68 nights by Dr Finsen for colour photography of Mars and on 68 nights with the micrometer by Mr Churms and Dr van den Bos for the measurement of known double stars.

Dr Finsen devoted much of his leisure time to the preparation of composite enlargements from the colour films of Mars obtained by him during the favourable oppositions of 1954 and 1956.

With the 9-inch refractor 109 and with the 6-inch photovisual refractor 31 occultations have been observed by Messrs Bruwer, Churms and amateur astronomers, members of the Transvaal branch of the Astronomical Society of Southern Africa, principally Messrs J. H. Botham and I. R. H. Brickett, who also made observations of planets, variable stars, etc., on 179 nights with the 9-inch refractor and rendered valuable assistance on visiting evenings and in other ways.

With the Franklin-Adams telescope at the Observatory's Annexe at Hartbeespoort Messrs Bruwer and Churms took 178 plates for minor planets and 23 for comets.

Counts of sunspots were made on 281 days.

The Time Service is operated by Messrs Hers and Seligmann.

During the year 1399 visitors were admitted on 37 nights.

Dr Muller was the Leiden Observer throughout the year.

Union Observatory Circular No. 115 and Annual Reports for 1953, 1954 and 1955 were distributed.

Papers by members of the staff published in other periodicals were:

W. S. Finsen: "The orbit of ϕ 307, δ Indi" (*M.N.A.S.S.A.*, **15**, 49, 1956); and "A suggestion for increasing the accuracy of position angle measurements of double stars" (*M.N.A.S.S.A.*, **15**, 60, 1956).

J. Hers: "The unit for frequency" (*Proc. I.R.E.*, **44**, 2, 1956).

P. C. Seligmann: "The determination of time for field observations" (*S.A. Survey Journal*, **8**, pt. 6, p. 15).

W. H. van den Bos: "Note on the orbit of ADS 1123" (*M.N.A.S.S.A.*, **15**, 39, 1956); and "General catalogues of double stars" (*M.N.A.S.S.A.*, **15**, 54, 1956).

Radcliffe Observatory, Pretoria

(*Director, Dr A. D. Thackeray, Radcliffe Observer*)

Equipment.—The Newtonian spectrograph, originally utilizing 2 prisms, has been modified to accommodate 1 prism in order to reach fainter objects with increased transparency in the violet. The box was made in the workshops

of the Royal Observatory, Cape, through the kind cooperation of H.M. Astronomer. This instrument, and the Newtonian grating spectrograph, have been used during the year.

Further progress has been made with the aluminizing tank and with the Coudé spectrograph, but neither has been completed.

Various improvements have been introduced into the Cassegrain photometer.

Three new meehanite wheels for the rotating turret were installed during 1956 February to replace ones which had suffered disintegration.

Observations. (*a*) *Radial velocities.*—The second stage of the Observatory's main programme on radial velocities of southern O and B type stars has been completed. The results, which include velocities and classifications of 152 faint stars with unknown or ill-determined velocities, and of 38 brighter stars with previously determined velocities, are being prepared for publication.

Some stars in this programme were added during the year on the basis of supergiant characteristics and critical longitudes for galactic rotation. As a result of special efforts with a dispersion of 19 A/mm at K, a few 9th mag. stars with distances probably exceeding 3 kpc have been shown to have two strong interstellar K components, presumably due to spiral structure. The observations suggest the presence of an inner spiral arm between Scutum and Norma, but no signs of it have been detected in longitudes preceding 295°.

In a programme on velocities of Me variables south of $-30°$ Dec and with $m_{\max} < 10$, the observations have been practically completed. Two or more spectra have been obtained for 77 stars.

Components of selected visual double stars have been observed with a view to possible determination of radial velocity parallaxes.

(*b*) *Globular clusters.*—In an important programme on radial velocities of southern globular clusters by Dr T. D. Kinman, Radcliffe Fellow, designed to round off Mayall's work, 55 spectra (86 A/mm) of 16 clusters with unknown velocities have been obtained. 32 of these spectra are of individual stars, the remainder of integrated light. In addition, 16 spectra have been obtained of 9 clusters with velocities already determined by Mayall. The programme includes work on the determination of standard wave-lengths for types F, G, and K at the dispersion used, and on comparison of spectra of the cluster stars and high-velocity stars in the Galaxy.

(*c*) *Magellanic clouds.*—A paper describing spectra of 4 long-period Cepheids in the Small Cloud and 6 in the Large Cloud, as well as the R CrB variable W Men, has been accepted by the Society. The discovery of 5 members of the Large Cloud with spectral types F to G and absolute magnitudes of the order of -9 has been reported. This represents an important outcome of continued work on stars in the general field of both Clouds. In the Small Cloud the loose aggregate NGC 371 has received particular attention. Work on stars and nebulosity near 30 Dor has also been continued.

(*d*) *Spectral classification.*—In addition to classifying the O and B type stars whose velocities have been measured, plates have been obtained of still fainter stars (9 to 11^{m}) with a view to selecting those with giant or supergiant characteristics for observations of velocity. In the course of this work, HDE 326823 has been discovered to be a peculiar hot emission object.

Stellar associations have received considerable attention. Work on M 25 and NGC 6087 has been completed, leading to the conclusion that the classical Cepheids U Sgr and S Nor are indeed members of these two clusters respectively.

Spectral types and radial velocities are being determined for stars in NGC 3293, NGC 6067 and IC 2944. Many O-type stars have been discovered in the latter association.

(*e*) *Individual stars.*—AM Cen: spectrophotometry of the continuum in this interesting star (resembling GP Ori) is reported in a contribution to the 1956 Liége Symposium.

HD 224113: a spectroscopic orbit is being derived from a series of observations.

HD 184552 (Aop): following Greenstein's report of variable velocity, a number of spectra have been obtained.

The following eclipsing variables have been studied: GL Car, AR Pav, AL Vel, AO Vel.

RR Tel: [Fe VI] has appeared as expected.

θ Oph: at the request of Dr A van Hoof series of spectra of this variable star were obtained on two nights.

V553 Cen and RT Tr A: Spectra have been obtained at the request of Dr C. Hoffmeister.

Eta Car: Evidence has been collected, including spectroscopic parallaxes of nearby stars, that this object must be regarded as a slow supernova, with an absolute magnitude between -13 and -14 at its maximum of 1841.

(*f*) *Direct photography.*—Photography of fields in and near the Small Cloud has been continued for a study of nebular counts.

Photographs of NGC 1466 and 2004 in two colours have been obtained for the purpose of studying colour-magnitude arrays. In collaboration with Dr H. C. Arp several long exposures of NGC 1866 in visual light were taken. Pairs of short exposures in two colours of many Large Cloud fields containing clusters and associations throw considerable light on the nature of these objects and assist in selecting interesting stars for spectroscopic study.

Dr Wesselink, during a visit to the Leiden Observatory, measured magnitudes and colours of several hundred stars in 47 Tuc from Radcliffe plates. The measures were made with the Leiden iris photometer by courtesy of Dr J. H. Oort.

Considerable progress has been achieved in the derivation of periods of variables in the Sculptor system by C. Jackson, Research Assistant.

Photographs of Eta Car through polaroid have demonstrated signs of polarization in certain portions of the surrounding halo. Similar photographs of the brightest portion of M8 failed to show sensible polarization.

(*g*) *Photoelectric photometry.*—A satisfactory system of standard colours was obtained for a number of standard stars in the E regions. Utilizing this system the colours of stars in the Magellanic Clouds and in the Galaxy have been compared. Magnitudes and colours of bright standard stars, kindly provided by Dr R. H. Stoy and Dr A. J. W. Cousins, have helped to eliminate uncertainties in the extinction suffered by Magellanic Cloud objects. Three-colour measures have been made in many LMC and SMC objects.

The sequence of magnitudes and colours of stars near 47 Tuc has been strengthened. Thanks are due to Dr H. C. Arp for instrumental assistance in the calibration of the faintest magnitudes in 47 Tuc.

3. *Guest Investigators.*—As in previous years, one third of the observing time has been allocated to astronomers from the Royal Observatory, Cape.

Dr H. C. Arp continued his population study of the Small Magellanic Cloud. 122 direct photographs were obtained and over 100 stars between magnitudes 12 and 19+ were measured photoelectrically. These observations will yield colour–magnitude diagrams to fainter than 19 in three areas (including the clusters NGC 419, 458) and in three more central areas (including NGC 330, 371) to a rather brighter limit.

Drs A. Muller and P. Th. Oosterhoff observed stars of B and other types spectroscopically, and also obtained direct photographs for calibrating sequences in the two Sagittarius fields being studied for variable stars.

Dr L. Rosino obtained 133 photographs of the globular clusters NGC 5824, 5986, 6273, 6304, 6558, 6569, 6637, 6715, 6864 in a search for variable stars.

4. *Buildings and grounds.*—A new room has been built on to the mechanic's house. A portion of the main entrance drive to the Observatory has been resurfaced.

5. *General.*—In a season of quality slightly below average the telescope was used profitably on 292 nights.

A study of seeing conditions has confirmed quantitatively the impression of many observers on the high veld that the best conditions are associated with calm nights and particularly with the absence of southerly winds. The quality of a night is rather closely correlated with the temperature range recorded in the turret from dusk to dawn.

Mr E. L. Johnson made observations for the JESO seeing expedition with a 10-inch reflector installed temporarily in the Observatory grounds. His observations are being compared with the Observatory's records of seeing with the 74-inch reflector.

On two nights in 1956 November television experiments on Mars and other objects were made at the Coudé focus of the 74-inch reflector with apparatus provided by Messrs Pye Ltd, Cambridge, which had been previously used at the Lamont Hussey Observatory, Bloemfontein.

Visitors.—In addition to Radcliffe staff, which during the present year included Dr T. D. Kinman, Radcliffe Fellow, and S. Archer, Radcliffe Student, the following used the 74-inch reflector during the year; from the Royal Observatory, Cape: A. W. J. Cousins, F. J. Driver, D. S. Evans, J. v. B. Lourens, W. Rasmussen, T. Russo, R. H. Stoy, L. Tilbury; from the Asiago Observatory: L. Rosino; from the Indiana and Mt Wilson and Palomar Observatories: H. C. Arp; from the Leiden Observatory: A. Muller, P. Th. Oosterhoff; and from Cambridge: B. V. Soames-Charlton. Other astronomers visiting the Observatory during the year included G. Courtes, J. Dommanget, H. Elsasser, C. Heynekamp, C. Jackson, E. L. Johnson, H. Siedentopf, and astronomers from the Union Observatory, Johannesburg.

Public visits to the Observatory have continued as in previous years and on September 21 members of the Astronomical Society of South Africa were admitted for a special view of Mars.

Nizamiah Observatory, Hyderabad

(*Director, Dr Akbar Ali*)

Astrographic equatorial.—The 8-inch photovisual object-glass of the astrographic telescope had to be kept in store on account of the repairs to the domes of the telescope houses and is expected to be put into operation early next year.

The copy for press of the catalogue of photographic doubles in the Hyderabad astrographic zones -17° to -23° was made ready during the year.

The work of deriving proper motions of stars in the regions common to the Oxford astrographic catalogues, zones $+32^\circ$ and $+33^\circ$, and the Potsdam Himmelskarte catalogues continued during this year also. 21 common regions from R.A. $1^h 7^m$ to R.A. $3^h 4^m$, containing 4118 stars, have been compared so far by S. Aravamudan and 358 proper motions were found. The corrections for the reduction of these relative proper motions to absolute motions are being derived.

Grubb equatorial.—11 occultations of stars by the Moon were observed and communicated to the Nautical Almanac Office for inclusion in the annual discussion.

The work of re-covering the domes of the two telescope houses with masonite was carried out during the months January to March. The covering was showing numerous depressions and, after the monsoon months, necessary repairs again had to be carried out. It is expected that the renewal work will be completed early next year. The observational work was greatly handicapped on this account. In addition, sky conditions were exceptionally unfavourable during the year.

Spectroheliosccope.—The Sun's disk was observed in Hα on 127 days for about $1^h 30^m$ on average per day. 17 flares, 2 of importance 3 and 15 below importance 3, were observed. 31 dark filaments with 13 shifts towards violet, 10 towards red and 8 towards both were also observed. 14 prominences with 8 shifts towards violet, 3 towards red and 3 towards both were noted. The data of the solar observations have been sent for incorporation in the *Quarterly Bulletin of Solar Activity* (Zürich).

Spectrohelioscopic observations were taken by Habeeb Alvi for 120 hours, by Ghouse Mohiuddin for 58 hours and Mohd. Ghouse for 3 hours, during the year.

Publications.—The following were sent for publication :

(1) " Stars with large proper motions in the Astrographic zones $+32^\circ$ and $+33^\circ$ List I " (*Journal des Observateurs*). (2) *The Hyderabad Astrographic Catalogue*, VIII, Part 2 (in the press) ; and (3) " Observations of Solar Flocculi made at the Nizamiah Observatory, Hyderabad, during 1951–1955 " (in the press).

Equipment.—The motors required in connection with the replacement of the old driving mechanism of the 15-inch Grubb by an electric drive have arrived. The relevant gearing is expected early next year, though orders for it were placed in England in 1955 October.

The University Grants Commission of the Government of India have sanctioned a sum of Rs. 12.47 lacs in their second Five Year Plan for modernizing the equipment of the Observatory and for the creation of a department of Astronomy in the Osmania University for graduate and post-graduate courses. Schemes have been forwarded to the authorities concerned for acquiring a 48-inch parabolic reflector with Coudé-Cassegrain focus and other modern auxiliary instruments.

Miscellaneous.—Lectures in practical astronomy were delivered to the graduate classes of the Osmania University.

The other routine work such as preparing the official calendar, seismological work and compilation of rainfall statistics of the Hyderabad State continued as usual.

On account of the reorganization of states in India, the rainfall statistics for future years will be compiled elsewhere.

Kodaikanal Observatory, Kodaikanal

(*Director, Dr A. K. Das*)

General.—On 1956 February 17 news was received of the sudden and untimely death of Professor M. N. Saha on the previous day. The observatory was declared closed for the afternoon of February 17 as a mark of respect to his memory. On November 23 news was received of the death of Mr John Evershed who was Assistant Director of the Kodaikanal Observatory from 1907 to 1911 and Director from 1911 to 1922 ; as a mark of respect to his memory the Observatory was closed for the rest of the day.

On a request from the International Astronomical Union, the Observatory agreed to participate in the international study of the development of sunspot-groups and in the cooperative photographic flare patrol during 1957–58.

Information regarding the observations (optical, magnetic and ionospheric) of the great solar flare of 1956 February 23 made at the Observatory was supplied on request to several scientific institutions and individual scientists in the U.K. and the U.S.A. A brief account of these observations will be found in the *Indian Journal of Meteorology and Geophysics* (**8**, No. 1, 1957).

In connection with the international photographic and visual patrol of Mars during the 1956 opposition, observations were made with the 20-inch Grubb Reflector and the 8-inch Cooke Refractor whenever weather permitted.

Steps were taken for placing final orders with Messrs Recherches et Etudes d'Optique et de Sciences Connexes, Paris, for an 8-inch Coronagraph for the Observatory. The optical parts for the Coronagraph will be constructed at the Institut d'Optique Théorique et Appliquée of Paris.

Scientific co-operation.—Exchange of spectroheliograms with foreign observatories was continued. 284 K-disk spectroheliograms for the period 1955 October–1956 September were sent to the Cambridge University Observatories. For the period 1955 July–1956 June 52 H-alpha disk and 53 K disk spectroheliograms were received from the Meudon Observatory, France, and 67 H-alpha disk and 84 K prominence spectroheliograms from the Mt Wilson Observatory, U.S.A.

Copies of daily spectroheliograms (disk in H-alpha and K and limb in K) were supplied in fortnightly batches to the Fraunhofer Institute, Germany, for the preparation of daily solar charts.

Two photoheliograms together with the relevant zero plates for certain specified dates in 1955–56 were supplied to the Astronomer Royal, Royal Greenwich Observatory, England.

Quarterly statements relating to solar flares were sent, as in previous years, to the Meudon Observatory, France, and to the Royal Greenwich Observatory, England.

Periodical statements of data of solar flares, relative sunspot numbers, ionospheric parameters and S.I.D.'s, information relating to central meridian passage of prominent sunspots, and forecasts of expected magnetic and ionospheric disturbances were supplied to a number of interested institutions in India.

Monthly median values of F2 layer critical frequency and maximum usable frequency factor for 3000 km transmission were supplied, as in previous years, to the Central Radio Propagation Laboratory, National Bureau of Standards, U.S.A. Quarterly statements of monthly median values of all ionospheric parameters were also supplied to the above institution and to the Radio Research Station, Slough, England. Magnetic storm data were sent every quarter to Professor John A. Simpson of the University of Chicago. The practice of broadcasting URSIGRAMMES relating to solar and geomagnetic activity was continued.

Routine observations.—Photoheliograms were made on 309 days and visual observations were possible on 305 days as compared with 289 days each in 1955. H-alpha disk, K disk and K prominence spectroheliograms were taken on 301, 293 and 267 days as compared to 275, 264 and 258 days respectively in the previous year. Observations with the spectrohelioscope were made on 295 days.

The average definition of the Sun's image on a scale in which 1 is the worst and 5 the best was 2·3. There were 18 days on which the definition was 4 or better.

Sunspot activity.—With the approach of the maximum of the solar cycle there was a marked increase in sunspot activity during the year. The yearly mean latitude of all the observed spotgroups in the northern and southern hemispheres was $24^\circ{\cdot}6$ and $21^\circ{\cdot}0$ respectively as against $25^\circ{\cdot}1$ and $25^\circ{\cdot}5$ for the previous year. Details of sunspot observations are given in the following table:

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
No. of new spot-groups N	6	11	16	14	16	11	14	11	18	18	11	12	158
No. of new spot-groups S	9	12	10	18	15	9	8	13	12	16	12	15	149
Mean daily no. of spot-groups	3·54	5·00	6·83	7·33	6·00	4·78	6·62	6·40	7·90	6·72	6·88	6·89	6·24
Kodaikanal daily relative sunspot number	62·6	88·3	107·9	115·0	102·7	81·1	99·6	116·6	132·5	110·9	129·3	126·5	106·1

Solar flares.—54 solar flares were observed during the year: 46 of intensity 1, 7 of intensity 2 and 1 of intensity 3.

Radio astronomy.—A receiver for 10 cm radiation specially constructed for Kodaikanal Observatory by the Division of Radio Physics, Commonwealth Scientific and Industrial Research Organization, Australia, was received.

Preliminary tests of its performance were made ; the antenna system of the Radio Telescope was under construction in the observatory workshop.

Geomagnetic observations.—Continuous photographic recording of *H, Z* and *D* with Watson and La Cour Magnetographs and visible recording of *H* with an Askania Field Balance were continued. Values of *H, D* and *Z* were determined weekly with QHM Nos. 254, 255 and 256 and a BMZ. Absolute measurements of *H* and *D* with the Kew Magnetometer and of the vertical force with an Earth-inductor were also made once every month.

One set of Eschenhagen variometers made by Askania Werke, Germany, was received, tested, and kept ready for installation at one of the field stations to be set up in South India during the coming International Geophysical Year.

During the year under review, 33 storms including 18 of sudden commencement type were recorded with ranges in H between 468 γ and 128 γ.

Ionospheric observations.—Round-the-clock ionospheric observations with the C.R.P.L. type C-3 Ionosphere Recorder were continued.

Regular field-intensity measurements were made on two frequencies.

Cosmic ray.—The Kolhörster Cosmic Ray Recorder, which had not been functioning for some time past, was again put into regular operation.

Seismology.—The Milne–Shaw Seismograph (E–W) component recorded 145 earthquakes.

Meteorology.—Meteorological observations with all the visual and self-recording instruments were carried out as usual.

Library.—53 books and 1899 periodicals were added to the library.

Research work.—Under the Research Training Scheme sponsored by the Ministry of Education, Government of India, one Senior and two Junior Research Scholars were working in the Observatory in 1956. The two Junior Research Scholars were released from the scheme in 1956 October after completion of their training.

The following problems in astrophysics and geophysics were under investigation :

1. The solar flare of 1956 February 23 and related geomagnetic and magnetic effects.
2. Study of contours of solar Fraunhofer lines, especially their variation from the centre of the disk to the extreme limb.
3. Study of variation of continuous absorption in the near ultraviolet solar spectrum.
4. Study of the red-shift of solar spectrum lines and its relation to the theory of relativity.
5. The distribution of calcium flocculi on the Sun's disk.
6. Study of magnetic fields of Venus, Mercury and the Moon.
7. Analysis of ionospheric and geomagnetic data collected in connection with the partial solar eclipse of 1955 December 14.
8. Scattering in F layer over Kodaikanal.
9. Total electron content per unit area of the ionosphere over Kodaikanal.
10. Lunar daily variation of magnetic field at Kodaikanal.

Publications.—The following papers and notes were either published or prepared for publication :

(1) " The Solar Flare of 1956 February 23 ", *Indian J. of Met. and Geophys.*
(2) " The Magnetic Field of Venus ", presented at the Indian Science Congress, 1957.
(3) " Effect of Lightning Discharges on Magnetographs ", *Nature.*

(4) "Quarterly synopses of results of solar, magnetic and ionospheric observations", *Indian J. of Met. and Geophys.*

(5) Annual Report of the Kodaikanal Observatory for the year 1955.

(6) *Kodaikanal Observatory Bulletins Nos.* 142 *and* 143, giving summary of results of solar and magnetic observations.

(7) Reports to the Society on (a) the work of the Kodaikanal Observatory, and (b) the prominence activity for the year 1955.

Uttar Pradesh State Observatory, Naini Tal

(*Chief Astronomer, Dr M. K. Vainu Bappu*)

Photoelectric photometry.—During the year a photoelectric photometer with D.C. amplifier and Brown recorder was put into operation on the 10-inch Cooke refractor. Integrated *B*, *V* measures of Mars during the recent close approach of the planet were obtained. A programme of study of the light variations of β-Canis Majoris stars has been initiated.

Stellar spectroscopy.—The spectrophotometry of two Wolf–Rayet binary systems HD 211853 and HD 193928 is now complete. The intensities of the emission lines have been measured for different phases of the two systems.

An analysis of the spectrum of the nucleus of Merrill's planetary nebula has been completed. A list of wave-lengths and intensities of the lines is ready for publication.

Some progress has been made in the study of the infra-red spectra of HD 192103 and HD 192163. The spectra of these bright Wolf–Rayet representatives of the carbon and nitrogen sequence were obtained with the former Cassegrain grating spectrograph of the Mt Wilson 60-inch telescope.

A detailed analysis of Coudé spectra of the shell star Pleione obtained at the Mt Wilson Observatory during the years 1943–46 is in progress. The results should give a picture of the physical conditions in the shell during the period studied.

The solar system.—Photography of Mars was carried out from August to October during the year, in yellow and red light, with the planetary camera attached to the 10-inch refractor.

Time section.—Two more quartz clocks have been received from Messrs Rohde and Schwarz of Munich. These have been installed, thus bringing the total in the possession of the Observatory to four.

Miscellaneous equipment.—An Esterline–Angus recording milliammeter has been acquired and will be used for airglow photometry. Some items of heavy equipment for the workshop were purchased during the year.

Commonwealth Observatory, Mount Stromlo

(*Dr A. R. Hogg, Acting Commonwealth Astronomer*)

Telescopes, buildings and equipment.—Considerable attention has been given to the optical and mechanical adjustment of the 74-inch reflector. The primary mirror has been aluminized in the plant recently installed. Further

progress on the 50-inch reflector has been delayed mainly in consequence of the concentration of work on the 74-inch telescope. However, the 50-inch mirror has been aluminized and some photoelectric observations made with it. A 50/65 cm Schmidt camera, the property of the University of Uppsala Observatory, has been installed on Mt Stromlo and satisfactory test plates obtained. The erection of a photographic zenith tube is nearing completion, and improvements have been effected to the driving system of the Yale–Columbia 26-inch refractor. The year saw the completion of the Uppsala Dome, the start of a darkroom in the 74-inch telescope dome, the carrying out of work to render this dome watertight, the installation of a fire-fighting system and the sealing of roads in the vicinity of the Observatory. Smaller items of equipment received include a Zeiss Spectrograph for use at the Newtonian focus of the 74-inch reflector, a monochromator and an Abbe comparator.

Astrophysical investigations.—The study of the Scorpio–Centaurus cluster by radial velocity observations has been continued, 366 bright southern stars have been typed according to the MK system, the Coalsack nebula has been investigated by three-colour photometry (photographic with photoelectric calibration), and similar observations have been made of the galactic clusters NGC 4755 and IC 4725. The survey of bright southern galaxies carried out with the Reynolds Reflector has been amplified by fifty plates taken with the 74-inch instrument and some radial velocities of galaxies have been obtained with the same telescope. A catalogue of galaxies has been prepared for publication and a new system of classification devised. A number of Cepheids and other variable stars have been observed. Transit observations and time-signals have been continued as in previous years.

Administration.—Preparations are in progress for the transfer of the administration of the Observatory from the Department of the Interior to the Australian National University. From 1957 January the Observatory will form the Department of Astronomy of the Research School of Physical Sciences of the Australian National University. Professor Bart J. Bok has accepted the Chair of Astronomy and will assume the Directorship of the Observatory from 1957 March.

Visitors.—During the year the following astronomers have visited the Observatory for various purposes namely Professor D. Brouwer (Yale), Dr Olin J. Eggen (Lick), Professor K. G. Malmquist (Uppsala) and Dr S. Gaposchin (Harvard).

Riverview College Observatory, Riverview, N.S.W.

(*Director, T. N. Burke-Gaffney, S.J.*)

During 1956, 445 plates were taken for the Variable Star Programme. Heavy rains during the early part of the year and poor seeing conditions (though the rainfall for the last six months was abnormally low) later in the year reduced the number of possible working nights. For the same reason, the number of occultations observed was less than average.

The Index to Riverview College Observatory Publications, Vol. 2, was completed and distributed. Reprint No. 10 (*The Photographic Light Curve of the Eclipsing Binary GW Carinae*, by L. Drake, S.J.) was also distributed.

During the year an International Business Machines Master Clock was installed, to supplement the original Contact Clock, which has been in service for close on fifty years and, as a consequence, is beginning to become unreliable.

The customary provision of astronomical and geophysical information to interested parties was continued ; much use was made of library facilities under the inter-library exchange scheme. Visitors' Nights show no falling off in attendance.

Staff shortage continues to be acute ; as heretofore, this makes itself most noticeable in the curtailment of time available for the production of publications. The outlook appears to be improving.

Sydney Observatory

(*Director, Harley Wood, Government Astronomer*)

The work on the Astrographic Catalogue has been continued. Volumes 33, 36 and 37 were printed and distributed and Volumes 38 and 41 are now in the hands of the printer. Volume 5 of the Melbourne section of the Astrographic Catalogue is almost completed in Paris and the manuscript of Volume 6 has been sent to Paris, where the volumes are being seen through the press by Dr J. Baillaud, using resources granted by the International Astronomical Union. Work is going forward on Volume 7.

The programme of observations of occultations predicted in the Nautical Almanac has been continued. The results for 1955 have been published and those for 1956 are being reduced. The photographic observations of double stars has continued.

We continued to observe minor planets which culminate south of the equator. By agreement with La Plata Observatory we concentrate more particularly on objects having even numbers while La Plata does the same for those with odd numbers. We have secured sets of observations of Ceres, Juno and Harmonia which are among those selected for purposes of fundamental astronomy. The wide-angle photography of zones of the southern sky for use in the preparation of catalogues of stars at Yale University Observatory has been completed. Professor D. Brouwer, Director of Yale University Observatory, has been here for periods between 1955 October and 1956 February in connection with this work. A new lens of focal length 72″ which covers a field 6° square and which was made by Taylor, Taylor and Hobson Ltd, has been installed for our positional work.

The civil and educational work of the Observatory has continued as in previous years.

Radiophysics Laboratory, Sydney

(*Chief, Dr E. G. Bowen*)

The most interesting results obtained by the radio astronomy group, which is under the direction of Dr J. L. Pawsey, relate this year to cosmic radio waves, both the continuous and line components. Sufficient results of the 85 Mc/s Mills Cross survey have now been reduced to show that there is gross disagreement with the corresponding Cambridge survey of discrete radio sources. On

19 Mc/s, initial results obtained with the second Mills Cross show that these observations are providing outstanding information on the distribution of H II regions in the galaxy. On 1420 Mc/s the survey of hydrogen line radiation in the vicinity of the galactic plane has given the general outline of spiral structure, thus completing the picture obtained by Leiden workers in the north, and has shown an interesting deviation from flatness of the hydrogen in the remote parts of the galactic disk.

On the solar side, work has been concentrated on the development of an equipment to give radio pictures of the Sun, a radioheliograph, and on extending the burst spectrometer to give position and polarization as well as spectrum.

On the theoretical side the theory of hydromagnetic waves in ionized gases has been further developed and a mechanism recognized which may well be a major factor in heating the solar atmosphere.

1. *Cosmic radio waves*

(*a*) *Continuous emission.*—The main equipment consists of the two Mills Crosses. The original one on a frequency of 85 Mc/s has arms 1500 ft in length and gives a beam 0°·8 in diameter. It has been in use for several years and its work of surveying the sky is nearly complete. The second one, frequency 19 Mc/s, arms 3500 ft, beam 1°·4, began operation this year. Observations on 100 Mc/s of the angular size of a number of discrete sources, using an interferometer with a baseline of several miles, have been completed. A survey at 600 Mc/s using a 36 ft mirror has also been completed. Several occultations (**18, 21**) have been observed with various equipments.

The reduction of the 85 Mc/s records is proceeding and now includes a systematic examination (**11**) of discrete sources in an area of the sky of about one steradian which is common to the Cambridge survey. It was known last year that the Sydney and Cambridge statistics were discordant. The new data show the discordance is due to gross disagreement between the positions of individual sources of the two surveys for all but the relatively intense ones. One, or both, of the surveys must be very seriously in error. The desirable check would be comparison with a third, independent, survey. But this requires a survey with angular resolution equal to, or preferably greater than, either of the present two surveys. Unfortunately no suitable equipment in this wave-length range appears yet to be planned. It should be possible to obtain valuable confirmatory evidence from the giant Manchester radio telescope at the short end of its wave-length range where the resolution is adequate, but exact correspondence with an 80 Mc/s survey would be conditional on the spectra of all radio sources being identical. The most plausible cause of the discrepancy appears to be confusion in the Cambridge results due to an unresolved background of faint sources. Because the resolution of the Sydney system is so much higher than the Cambridge one, the corresponding effect should become important at a very much lower intensity level, actually below the sensitivity limit. The Sydney results do not show a departure from the $-3/2$ intensity–number distribution power law greater than known experimental uncertainties so that the interesting cosmological consequences advanced by Cambridge workers must be regarded as non-proven.

A small area was examined carefully by Dr R. Minkowski in relation to Palomar–Schmidt plates for possible identifications. Other areas have been examined but not systematically. From such work a picture is emerging of the emission to be expected from various types of objects, normal spiral galaxies,

emission nebulae (**8, 10**), novae and supernovae (**9**). But this leaves the great majority of sources unidentified and it is probable that, at least away from the Milky Way, abnormal galaxies which are intense radio emitters comprise the majority of radio sources.

The pencil beam technique is particularly valuable in examining complex regions. In the direction of the galactic centre, for example, it showed that the source in that direction is composed of at least two distinct parts (**7**): a relatively small H II region which is bright at short wave-lengths but appears in absorption at 85 Mc/s, and a more extended background which is dominant at the longer wave-lengths. This complex had been assumed by other workers to be a single physical entity.

The frequency of the 19 Mc/s Cross was chosen to be as low as practicable in view of ionospheric effects. At this period of high sunspot numbers, radio interference is severe and limits observations to about 6 hours each day. Scintillations of radio sources are also troublesome. Nevertheless the observations open up a new approach to the study of H II regions (**20**). As the galactic equator is approached the brightness begins to rise and then falls to a low value in an irregular trough along the galactic equator. This trough is clearly due to absorption in H II regions. The initial rise is conclusive evidence that a part, probably the major part, of the radio emission from the disk is of non-thermal origin. The computed absorption in H II regions at this frequency is very high and it is probable that a spiral arm should be quite opaque. Consequently the peaks and hollows which occur along the trough near the galactic equator are likely to play a most useful role in indicating the positions of H II clouds and spiral arms in the vicinity of the Sun.

Towards the other end of the spectrum a survey on a frequency of 600 Mc/s was completed (**15, 16**). A considerable proportion of the radiation at this frequency is thermal emission from H II regions, the precise fraction being still a source of controversy, but the form of the distribution is very different from the 19 Mc/s pattern of absorption because the 600 Mc/s radiation comes from both far and near.

A series of measurements on 100 Mc/s of source sizes was completed using low resolution aerials in an interferometer of several miles separation. Several dozen sources were measured. They mostly ranged in size from about 1 to 3 minutes of arc, corresponding to brightness temperatures of a few million degrees. No sources having a surface brightness approaching that of the Cygnus source were discovered.

(*b*) *Hydrogen line studies.*—A few observations were taken to complete an extensive survey of 21 cm line emission from near the plane of the galaxy and the initial reduction of results is nearly complete. The results complement the Leiden observations and complete the picture of spiral structure in the galaxy. They also give the shape of the disk population of neutral hydrogen. The disk is about 250 parsec thick and surprisingly flat over the central regions. In the outer parts in the vicinity of the Magellanic Clouds, however, it shows a distinct bend towards the Clouds, and a similar bend in the opposite sense on the other side. The results will also provide information on rotation in the galaxy. Line profiles in the galactic plane in directions inclined equally to the galactic centre are not symmetrical but the effect is suspected to be due rather to non-symmetrical distribution of matter than to non-circular orbits.

In collaboration with the California Institute of Technology, the suggestion has been made that with future equipments it may be possible to use the Zeeman splitting of 21-cm absorption lines to measure interstellar magnetic fields in localized regions of the galaxy (**1**). If so, this would open a new field of fundamental importance to galactic structure and cosmology.

2. *Solar radio waves*

Observations of solar radio bursts have led to hypotheses that certain types are directly associated with the ejection (1) of corpuscles causing magnetic storms and (2) of cosmic rays. These hypotheses invite more detailed observations and the radio spectroscope is being modified so that in addition to spectra it will give data on position and polarization. Simultaneous optical observations are also being taken by the Division of Physics, C.S.I.R.O. Initial results indicate a moderately close association between flares and " Type III bursts " (those showing a rapid frequency drift).

The new " radio heliograph " being constructed by W. N. Christiansen for giving 21 cm pictures of the Sun is nearing completion. It consists of two broadside arrays of 32 paraboloids arranged in the form of a cross. The respective outputs are multiplied together as in the Mills Cross and the overall directional response consists of a small number of well-separated circular beams, each 2 or 3 minutes of arc in diameter. These will be arranged to scan the Sun one at a time, television-wise, and so produce the picture. It is expected that both this and the metre wave-length burst equipment should be operating before 1957 June and will be run over the period of the International Geophysical Year.

An interesting occultation of the Crab Nebula (**21**) by the corona of the Sun was observed which indicated the occurrence either of absorption or wide angle scattering. This does not conform with the current theory.

Single frequency intensity records are being taken on frequencies of 200, 600 and 1400 Mc/s. The solar radio emission section of the *Quarterly Bulletin on Solar Activity* is edited by S. F. Smerd in this Laboratory. Mr Smerd has been asked to edit the corresponding section of the I.G.Y. volume on solar activity.

3. *Planetary radio emission.*—Observations were made of radio waves from Jupiter using equipment which could give directional identification even on short bursts of emission. No evidence was found for bursts from Jupiter of duration less than about half a second so that the radiation appears analogous more to solar noise than to terrestrial atmospherics. The tendency for emission to originate in particular regions on the planet was again evident. The radiation appears stronger on 20 Mc/s than on either 15 or 25 Mc/s.

Records obtained at various times were examined for radiation from Venus. None could be identified as originating on this planet.

4. *Radio-star scintillations.*—Analysis of several years' observations of radio-star scintillations has thrown light on the controversy as to whether the scintillations originate in ionospheric irregularities in the F_2 layer or in the E layer. The clear result (**25**) has emerged that scintillations observed at Sydney at moderately low altitudes are associated with F_2 irregularities by night (winter observations) and with sporadic E irregularities by day (summer observations).

5. *Theoretical.*—The properties and effects of hydromagnetic waves in ionized gas have been studied (**17**), in particular the remarkable effects of a

small proportion of neutral atoms. These cause a large increase in heating of the gas and may account for chromospheric heating. They may also cause transfer of energy from the wave to energy of excitation and ionization of the gas components, a process which may be basic in solar flares and other observed effects (**13**). The theory has been extended to interstellar gas with similar results.

" Strong " hydromagnetic waves, in which the field is grossly distorted, have been investigated. These may explain other observed solar phenomena and the generation of some cosmic magnetic fields.

Further work has been carried out on the effects of finite aerial resolution on the observation of brightness distributions (**2, 3, 22**). In particular the relation between " strip " scanning and " pencil-beam " scanning has been formulated (**22**).

6. *Visitors.*—We were pleased to welcome during the year : Dr R. Minowski, who spent two months here making a study of radio sources in relation to optical information ; Dr R. Q. Twiss, who began a two-year fellowship here ; Professor B. J. Bok, who visited the Laboratory during a preliminary visit to Australia prior to taking up his post as the new director of the Mt Stromlo Observatory ; and Dr Merle Tuve. A symposium on Radio Astronomy in Australia was held during September which was attended by about 70 persons.

7. *Papers published, or accepted for publication, during* 1956:

(**1**) Bolton, J. G. and Wild, J. P., " On the Possibility of Measuring Interstellar Magnetic Fields by 21 cm Zeeman Splitting ", *Ap. J.*, **125**, 296–297, 1957.
(**2**) Bracewell, R. N., " Strip Integration in Radio Astronomy ", *Aust. J. Phys.*, **9**, 198–217, 1956.
(**3**) Bracewell, R. N., " Two-Dimensional Aerial Smoothing in Radio Astronomy ", *Aust. J. Phys.*, **9**, 297–314, 1956.
(**4**) Gum, C. S., " The Extent and Excitation of the Large H II Region in Vela-Puppis ", *Observatory*, **76**, 150–153, 1956.
(**5**) Kerr, F. J. and de Vaucouleurs, G., " The Masses of the Magellanic Clouds from Radio Observations ", *Aust. J. Phys.*, **9**, 90–111, 1956.
(**6**) Kerr, F. J. and Shain, C. A., " Reflection of Radio Waves from the Moon ", *Nature*, **179**, 433, 1957.
(**7**) Mills, B. Y., " The Radio Source near the Galactic Centre ", *Observatory*, **76**, 65–67, 1956.
(**8**) Mills, B. Y., Little, A. G. and Sheridan, K. V., " Absorption of 3·5 m Radiation in the Optical Emission Nebula NGC 6357 ", *Nature*, **177**, 178, 1956.
(**9**) Mills, B. Y., Little, A. G. and Sheridan, K. V., " Radio Emission from Novae and Supernovae ", *Aust. J. Phys.*, **9**, 84–89, 1956.
(**10**) Mills, B. Y., Little, A. G. and Sheridan, K. V., " Emission Nebulae as Radio Sources ", *Aust. J. Phys.*, **9**, 218–227, 1956.
(**11**) Mills, B. Y. and Slee, O. B., " A Preliminary Survey of Radio Sources in a Limited Region of the Sky at a Wave-length of 3·5 m ", *Aust. J. Phys.* **10**, 162–194, 1957.
(**12**) Pawsey, J. L., " Radio Astronomy " (Presidential Address to Section A of A.N.Z.A.A.S., Melbourne, August 1955), *Aust. J. Sci.*, **18**, 3 (a), 27–35, 1956.
(**13**) Piddington, J. H., " Solar Atmospheric Heating and Flares ", *Observatory*, **76**, 21–23, 1956.
(**14**) Piddington, J. H., " Growing Electric Space-Charge Waves ", *Aust. J. Phys.*, **9**, 31–43, 1956.
(**15**) Piddington, J. H. and Trent, G. H., " Cosmic Radio Sources Observed at 600 Mc/s ", *Aust. J. Phys.*, **9**, 74–83, 1956.
(**16**) Piddington, J. H. and Trent, G. H., " A Survey of Cosmic Radio Emission at 600 Mc/s ", *Aust. J. Phys.*, **9**, 481–493, 1956.
(**17**) Piddington, J. H., " Solar Atmospheric Heating by Hydromagnetic Waves ", *M.N.*, **116**, 314, 1956.

(18) Rishbeth, H., " An Investigation of the Radio Source O6N2A in Gemini ", *Aust. J. Phys.*, **9**, 494–504, 1956.
(19) Shain, C. A., " 18·3 Mc/s Radiation from Jupiter ", *Aust. J. Phys.*, **9**, 61–73, 1956.
(20) Shain, C. A., " Galactic Absorption of 19·7 Mc/s Radiation ", *Aust. J. Phys.*, **10**, 195–203, 1957.
(21) Slee, O. B., " Occultation of a Radio Source by the Solar Corona ", *Observatory*, **76**, 228–231, 1956.
(22) Smerd, S. F. and Wild, J. P., " The Effects of Incomplete Resolution on Surface Distribution Derived from Strip-Scanning Observations, with Particular Reference to an Application in Radio Astronomy ", *Phil. Mag.* Ser. 8, **2**, 119–130, 1957.
(23) Wild, J. P., " Solar Radio Noise and the Study of Corpuscular Streams from the Sun ", *Solar Eclipses and the Ionosphere* (*Special Suppl. Vol.* 6 *to J. Atmos. Terr. Phys.*) 1956.
(24) Wild, J. P. and Roberts, J. A., " The Spectrum of Radio-Star Scintillations and the Nature of Irregularities in the Ionosphere ", *J. Atmos. Terr. Phys.*, **8**, 55–75, 1956.
(25) Wild, J. P. and Roberts, J. A., " The Regions of the Ionosphere Responsible for Radio-Star Scintillations ", *Nature*, **178**, 377–378, 1956.
(26) Wild, J. P. and Zirin, H., " On the Association of Solar Radio Emission and Solar Prominences ", *Aust. J. Phys.*, **9**, 315–323, 1956.

Perth Observatory

(*Director, Mr H. S. Spigl, Government Astronomer*)

Two staff appointments have now been made, and orders have been placed for certain of the equipment mentioned in last year's report. Progress can be reported with regard to the major overhaul of the 6-inch transit instrument.

The civil work of the Western Australian Standard Time service, the Port Hedland tide tables, astronomical phenomena for various places throughout the State, and information for the press, radio, and public, were maintained as in previous years, while the regular evening and afternoon visits have attracted large numbers of the public.

In seismology, the full year's recordings of the Milne–Shaw and Lamont vertical seismographs of 91 earthquakes have been analysed and distributed to cooperating stations. Preliminary reports of a number of strong movements, originating within 5000 km of Perth, were cabled to the U.S. Coast and Geodetic Survey.

The results of 24 occultations were sent to H.M. Nautical Almanac Office for inclusion in the discussion. During the opposition of Mars, a number of drawings were made in connection with the International Mars Committee's study of clouds on Mars.

Plans to cooperate in the work of the I.G.Y. were furthered in the Photographic Moon Position Programme, and steps have been taken to organize and coordinate a regular auroral watch from various parts of the State. The director has agreed to act as the coordinator of the local effort in " Moonwatch ". In the seismological field it has been arranged to cooperate in observations of the microseismic movements to be studied in conjunction with meteorological phenomena.

The Observatory was favoured with visits by Professor Brouwer, Dr Tuve, and a number of visitors attending scientific and professional conferences held at Perth during the year.

Geophysical Observatory, Christchurch, N.Z.

(*Superintendent, Dr J. W. Beagley*)

Continuous recordings of ionospheric characteristics at Godley Head, Christchurch, Rarotonga, Cook Islands, and Campbell Island were maintained during the year. Preparations were made for extending the programmes at the present stations during the International Geophysical Year and setting up a new recording station at Scott Base, McMurdo Sound.

The prototype panoramic ionosonde became the Godley Head standard recording equipment from August of this year. Canterbury College Industrial Development Department and Observatory physicists, having achieved a satisfactory recording standard with the prototype, built a second model which has already been forwarded to Scott Base. A third panoramic ionosonde is under construction for installation at Rarotonga in April of next year. The J. 28 Ionosonde ex Godley Head has been redesigned and is being rebuilt at the Observatory to replace the manual recorder at present at Campbell Island. It is anticipated that the three panoramics and the J. 28 will be operating satisfactorily at the beginning of the I.G.Y.

Ionosphere observers for all stations were trained to undertake the I.G.Y. programme and in addition two observers were given instruction for the manning of the Cape Adare station in Antarctica where the United States of America and New Zealand are cooperating on the scientific programme.

Progress has also been made with the construction of the meson telescope for recording cosmic radiation at Invercargill during the I.G.Y. and it is expected to be set up there during the early half of next year. Continuous recording of cosmic radiation at Christchurch has been maintained.

Research work on the ionosphere electron density project has continued. The conjugate stations of Maui and Rarotonga have been investigated and a N-S anomaly demonstrated. Storms in the ionosphere have been studied to provide information on the relative importance of gaseous and magnetic forces at the F_2 level. Special interest has been taken in night-time storm characteristics. Heights of travelling disturbances were investigated to find the region most favourable to their occurrence.

Publication of ionosphere data annually has been commenced.

Carter Observatory, Wellington, N.Z.

(*Director, Mr I. L. Thomsen*)

Telescope demonstrations and lectures were given on Friday evenings from February to December. The attendances for the year totalled 3239. Interest was aroused by the opposition of Mars and there was a record attendance of 560 on September 7.

Editorial duties for the Royal Astronomical Society of New Zealand were carried out at the Observatory, and assistance given to amateur societies and individuals whenever possible.

The Lecture Room has been made available for meetings of the Royal Astronomical Society of New Zealand and the Astronomy and Geophysics Section of the Wellington Branch of the Royal Society of New Zealand.

For instructional purposes, 3-inch refracting telescopes were on loan to four secondary schools in New Zealand.

Besides external lectures to many institutions, articles and information have been supplied to the press as required. Astronomical data were also supplied to calendar printers, architects, solicitors and Government Departments as required.

Observations of sunspots, together with those collected from selected amateurs, totalled over 650. Owing to the pressure of work, regular routine observations with the Hale spectrohelioscope were temporarily suspended, but it is expected to institute a programme for the International Geophysical Year.

The increasing auroral activity in sympathy with solar activity has been most marked. Reports have been received from voluntary observers throughout New Zealand, Tasmania and Australia. The scientific parties on Campbell Island have continued to supply most valuable data.

The auroral catalogue covering the last 25 years was completed and research on the data contained therein commenced. This work has been possible through a contract with the Air Force Cambridge Research Centre, U.S.A. Through the agency of the same contract, New Zealand has been enabled to have on loan three All-Sky Cameras, an auroral patrol spectrograph and a high-dispersion auroral spectrograph for use in setting up I.G.Y. stations. This valuable assistance enables the New Zealand region to take full advantage of its unique position in the forthcoming programmes.

Short-term ionospheric disturbance forecasts were issued to the Post and Telegraph Department, New Zealand Broadcasting Service and the Royal New Zealand Navy.

During the 1956 opposition of Mars, 66 drawings were made by three observers with the 9-inch refractor. Other planetary or stellar work was not possible owing to pressure of the remaining work. Much material from previous years is still awaiting final reduction and preparation for publishing.

Canterbury University College Observatory, N.Z.

(*Director, Mr K. W. Roth*)

The 6-inch refractor in parallactic mounting was made available to the public every Friday evening, and during August and September for one or two extra sessions per week, because of the great interest aroused by the opposition of Mars. The attendance was well over one hundred for several weeks, and altogether between two and three thousand people had a viewing of Mars and of other objects in season.

As the Observatory has no accessory equipment, either chronometer, or photographic camera, or spectrographic attachment, no serious work could be undertaken with the telescope, research work being undertaken by radar technique.

Godlee Observatory, College of Science and Technology, Manchester

(*Curators, Manchester Astronomical Society*)

Work at Godlee Observatory during 1956 has proceeded on similar lines to that of previous years. Thursday evenings have been reserved for the use of members of the Society, who have made good use of its facilities. Arrangements were also made for members of Manchester University Astronomical Society to take part, and they have been active, especially on Saturday evenings.

A very fine spectroscope has been presented to the Manchester Astronomical Society by Mr A. P. Okell and his brother, and a suitable adaptor for its use with the 8-inch refractor is being made.

As usual, parties of visitors from various educational and cultural organizations and youth clubs have been welcomed, and have spent the evenings on observational work or on lantern lectures when the weather has been bad.

Routine solar observations have been made when the weather permitted, but have been handicapped by more than usually cloudy weather.

Observations of double stars have continued, and a considerable number of lunar and stellar photographs have been taken.

Mr R. Barker's Observatory, Cheshunt, Hertfordshire

The recent opposition of Mars was spoiled by persistent veiling that entirely shrouded the planet.

Only outlines of the dark maria and a few of the bolder canali could be traced with difficulty. Most of the oases and carets were invisible.

An extensive system of very delicate, difficult lunar clefts has been recorded south of Condamine, on the rugged area between Plato and Promontory Laplace. Altogether, seeing conditions were indifferent almost throughout 1956.

Dr J. L. Haughton's Observatory, Littleton, Nr Winchester, Hants.

Latitude:	N 51° 5′ 25″·6
Longitude:	W 1° 21′ 3″·2
Altitude:	246 ft.

The observatory was moved from Charmouth in 1955 and re-erected in Littleton during the first half of 1956. As this is the first report from there the co-ordinates are given above. Owing to the very bad weather only three occultations were observed during the half year.

The Sun was observed from time to time and a few drawings of spots were made.

The observatory was visited by 67 people.

Mr M. B. B. Heath's Observatory, Kingsteignton, Devon

Visual observations of the Sun for spot counts were made on 79 days. Daylight observations included Mercury on 29 days with 4 drawings and Venus on 97 days with 22 drawings. Mars was observed on 33 nights and 16 drawings made; Jupiter on 9 nights, 8 satellite phenomena being timed, also the eclipse of III by II on March 12 and occultations of I by II on March 25. Saturn was observed on 15 nights and one drawing made.

Mr F. M. Holborn's Observatory, Peaslake, Surrey

During 1956, 1496 observations were made of 72 variable stars and novae on 135 nights. Mars and comet 1956 h were also observed. The Sun was observed on 252 days for spot counts and naked-eye spots. Work on faint stars was impossible for three months owing to damage to the 12¼-inch mirror which was eventually replaced by a 12-inch Pyrex mirror by H. Wildey.

All records were communicated to the British Astronomical Association except those of Gamma Cassiopeiae which were reserved for the Norman Lockyer Observatory.

Mr Patrick Moore's Observatory, East Grinstead, Sussex

Work carried out in 1956 was similar to that of previous years. Observations were confined mainly to the Moon and Venus, the lunar work being largely concerned with investigations of special features such as domes. Seventy drawings of Mars were also made. The 12½-inch reflector remains the main instrument.

Mr G. E. Patston's Observatory, Eastbourne, Sussex

Observations have been considerably interrupted consequent on the sale of the observatory's site. The 12-inch reflector was twice partly dismantled and re-erected, and suffered slight damage when the observatory was burgled. Removal may become unnecessary but an alternative site is available. Altogether another " year of confusion ".

Data for two additional Z Cam-type stars, TZ Persei and CN Orionis, received from the B.A.A. Variable Stars Section Director, to whom all records are sent, have been added to the programme on which it is hoped that work will be continuous in 1957.

Dr W. H. Steavenson's Observatory, Cambridge

Photometric observations of Nova Persei have been continued with the 30-inch reflector.

On several evenings during the spring and early summer Mr T. W. Rackham used the telescope for photography of Venus in integrated and ultra-violet light.

Physical observations of three comets, Mrkos, Olbers and Arend–Roland, were made during the year.

The telescope has been in regular use for demonstrations to undergraduates and other visitors to the Observatories.

Dr R. L. Waterfield's Observatory, Ascot

During the year 23 plates were exposed with the 6-inch Cooke Triplet on comets: Haro-Chavira 5, Olbers 6, Mrkos 3, Arend–Roland 5, and search plates 4. Towards the end of the year a machine suitable for the measurement of comet positions was acquired; and with it the position of comet Arend–Roland was obtained on three nights during November and December. Four occultations of stars by the Moon were observed and the times communicated to the Nautical Almanac Office. Drawings and observations of Mars were made on 11 nights during the opposition; and in August and September observations were made of an unusually bright spot on Venus.

Dr H. P. Wilkins' Observatory, Bexleyheath, Kent

The 15¼-inch reflector has been moved to a more advantageous site and fitted with a driving clock, and is now housed in a shelter 10 ft in diameter, equipped with shutters and capable of rotation.

The instrument has been used for the verification of and additions to minute details shown on photographs of selected lunar formations taken at Mt Wilson and Pic-du-Midi Observatories by Dr Dinsmore Alter and Dr Dollfus respectively. The formations include Ptolemâeus, the Straight Wall and Aristarchus. Observations of the earthlit portion of the disk and of occultations have been continued. Several drawings of Mars were secured with the 15¼-inch and the Meudon 24-inch Cassegrainian reflector.

As usual, the observatory has been open to visitors on Saturday nights.

REPORTS ON THE PROGRESS OF ASTRONOMY

THE DETERMINATION OF COSMIC ABUNDANCES

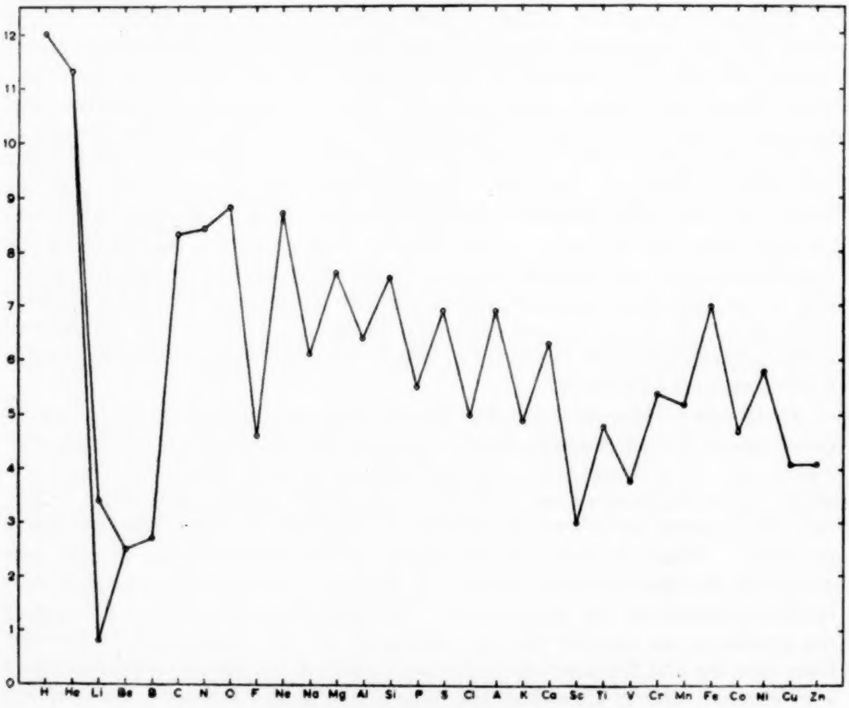
Introduction: the concept of "cosmic matter".—The hypothesis that all celestial objects have essentially the same chemical constitution was introduced only relatively recently in astrophysics. Clarke suspected in 1889 that the abundances of the elements in the Earth's crust would prove to be meaningful; that they even could inform us about the way in which the atoms had evolved from Crookes' original "protyle". A parallelism between the abundances of the elements in the Earth, in the stony meteorites, and in the Sun was suggested by Russell in 1914, and already several years earlier in his lectures. In the same year, he expressed the opinion that the apparent dissimilarity of stellar spectra was due to variations of temperature. But the great step was made, when Megh Nad Saha (1921) explained how the effects of temperature and pressure on a gaseous mixture of one and the same composition may be understood on the basis of Bohr's atomic model and how they reproduce quantitatively the observed spectra. The first comparisons between the abundances in the Earth, the meteorites, and the stars are found about 1925, for example in the book of Miss Payne (1925). Since then a great effort has been made in all branches of geo- and astro-physics in order to establish the chemical composition of the individual celestial bodies; and the existence of "*cosmical matter*" with a standard constitution was gradually confirmed. Later, however, numerous minor differences were discovered, which became a great stimulus towards further research and theory.

Obviously we should like to ascertain as well as possible the overall chemical composition of each celestial body. But our knowledge is too scant for such a purpose. It is therefore *provisionally* assumed that cosmic matter has everywhere the same composition. This will be at least partly true, either within the solar system, or within population I of the stars, or perhaps even more generally. What we know of cosmogony makes probable that, during their evolution, changes will have occurred in some of these celestial bodies, mainly in the abundance of the light atoms. The method of work is thus to compare the results of the analysis for the individual celestial objects and to combine them into one and the same table of abundances. If for certain elements we find a divergence, clearly exceeding the uncertainty of our methods, we conclude that there are differences of origin or that changes must have occurred, and we carefully note the differences in view of an individual chemical history of each celestial body. It is easily understood that there will remain many doubtful cases, in which our decision will be influenced by other considerations. It is then necessary to consider the relation between the chemical composition and the distribution in space, the space velocities, the probable cosmogonical processes and the nuclear properties of the individual elements.

It would be useful if abundances could be always quoted in the same notation. In general we list $\log N$, the logarithm of the number of atoms of the several elements in a given amount of matter. We put $\log N_{\mathrm{H}} = 12$ for hydrogen, in order to avoid negative figures for the rare elements. Suess and Urey take for comparison the silicon abundance and put $\log N_{\mathrm{Si}} = 6$.

Among the general papers devoted to the problem of cosmic abundances in the last years, we quote the 1948 symposium of the I.A.U. at Zürich, the

reduction by Kuiper (1952) and the discussion by C. de Jager (1953 *b*). The very important paper of Suess and Urey (1956) combines the data of observation with certain cosmogonical assumptions and with our knowledge of nuclear properties into a beautiful synthesis, but does perhaps not sufficiently stress the distinction between these three sources of information. The most authoritative and complete general review is probably Aller's book *Chemical Composition of the Universe*, to be published soon by the Interscience Press. The journal *Geochimica et Cosmochimica Acta*, published since 1951, is of special interest for our subject.



The abundances of the first 30 elements.

The Earth.—Our direct knowledge about the composition of the Earth refers only to the uppermost layer of its crust, and even there the abundances are so different from one sample to another that often a reliable mean value can hardly be obtained.

A good impression of the difficulties of the subject and of the large amount of literature is found in the standard handbook of Rankama and Sahama (1950). Suess and Urey estimate that errors of more than a factor of 10 occur for several elements. On the other hand a study of the minerals is often the only way to evaluate the amount of the rare elements and the isotopic constitution.

Goldschmidt (1954) based his classic investigations on the distinction between the metal phase, the sulphide phase and the silicate phase, which are observed in meteorites and are assumed to constitute also the Earth; he supposed that

all the elements would be distributed in equilibrium proportions between them. The relative amounts of matter in the three phases are found by the different authors according to indirect arguments, leading to considerably divergent results: they adapt their values either to the solar abundances or to those in meteorites (which are themselves dubious).

All considerations would be considerably modified if the hypothesis of Ramsey and others could be confirmed, and if the interior of the Earth could be found to have mainly the same composition as the mantle. However the very data on abundances do not seem to be in favour of this hypothesis. If there was no iron-nickel core, the whole Earth would have about the composition of the mantle, and the terrestrial abundances of several elements would be very different from the solar values; especially the Ni : Fe ratio would be too small.

Most of the tables which have been recently published either refer to the crust and not to the Earth as a whole or have been obtained by combining the terrestrial and the cosmical data. We quote (in modified form) the estimates

TABLE I

Cosmical abundances

Element	Earth's Crust, Rankama–Aller	Entire Earth, Mason (1954)	Meteorites, Urey (1956	Sun	Early Stars	Planetary Neb., Aller (1957)	Mean for Pop. I
1 H	6·17	...	...	12·00	12·00	12·00	12·00
2 He	...	...	...	...	11·30	11·3	11·3
3 Li	3·57	...	3·40	0·83	...	...	0·8–3·4
4 Be	2·40	...	2·60	2·43	...	...	2·5
5 B	2·51	...	2·70	...	...	...	2·7
6 C	4·49	...	...	8·28	8·36	...	8·3
7 N	3·58	...	...	8·15	8·52	8·4	8·4
8 O	7·53	7·98	...	8·68	9·01	8·8	8·8
9 F	4·63	...	3·88	...	...	5·4	4·6
10 Ne	...	...	...	...	9·02	8·0	8·7
11 Na	5·15	5·52	6·04	6·14	...	...	6·1
12 Mg	6·00	7·58	7·36	7·27	8·04	...	7·6
13 Al	6·54	5·95	6·38	6·06	6·69	...	6·4
14 Si	7·06	7·39	7·40	7·43	7·69	...	7·5
15 P	4·65	4·09	5·10	...	5·91	...	5·5
16 S	4·27	6·67	6·39	6·91	7·51	7·8	7·0
17 Cl	4·01	...	4·72	...	...	5·3	5·0
18 A	...	...	...	...	...	6·9	6·9
19 K	5·88	4·99	4·90	4·87	...	...	4·9
20 Ca	6·02	5·92	6·09	6·23	6·50	...	6·3
21 Sc	2·71	...	2·85	3·12	...	...	3·0
22 Ti	5·03	5·67	4·79	4·82	...	...	4·8
23 V	3·53	...	3·74	3·90	...	...	3·8
24 Cr	3·65	3·99	5·30	5·45	...	...	5·4
25 Mn	4·32	5·94	5·24	5·24	...	...	5·2
26 Fe	6·01	7·53	7·18	6·83	...	...	7·0
27 Co	2·66	5·26	4·66	4·75	...	...	4·7
28 Ni	3·20	6·39	5·84	5·73	...	...	5·8
29 Cu	3·00	...	3·73	4·41	...	...	4·1
30 Zn	3·29	...	3·65	4·46	...	...	4·1

of Rankama (1954) as modified by Aller (*Chemical Composition*, Ch. 4), which refer to the crust; and those of Mason (1952, 1954), which refer to the whole Earth but to a limited number of elements only (see Table I).

The major planets.—An attempt to derive the inner structure of the major planets was made by Ramsey, applying the equation of state for hydrogen at high pressures and taking into account the phase transition and the formation of a metallic phase. He assumed that hydrogen and helium were the main constituents and even tried to derive the ratio of their abundances. According to the degree of concentration of helium and possibly some of the higher elements, log He/H was found to vary between $-1{\cdot}12$ and $-1{\cdot}32$ for Jupiter; between $-0{\cdot}81$ and $-0{\cdot}94$ for Saturn, (Miles and Ramsey, 1952). This work was criticized and improved by Abrikosow (1954), who confirms that the major planets have a certain helium content but does not yet dare to estimate its amount.

Meteorites.—The three phases, silicate, sulphide and metallic iron, occur also in meteorites. That the elements would be distributed between them in equilibrium proportions is not generally true, since the concentration of the individual elements in each of these phases shows considerable variation. Special complications occur for the sulphide phase, but this represents only a negligible fraction of the total amount of meteoritic matter (probably less than 8 per cent).

The ratio between the mass of the stone meteorites and of the iron meteorites cannot be determined directly from the whole of the meteorites thus far collected, because the first category is much less easily recognized and preserved than the second one. Several authors have assumed that the proportion would correspond to that between the mantle and the core of the Earth; but this is dubious, for

(1) the ratio of mantle to core seems to vary from one terrestrial planet to another;
(2) it is not certain that the core consists of iron; and
(3) there is no conclusive evidence that meteorites are fragments of a terrestrial planet.

Urey, from cosmogonic arguments, concluded that the more or less constant composition of the chondrites must be considered as typical for the non-volatile constituents of the planetary system, and assumed the proportion silicate 100 : sulphide 7 : metal 10·6. The uncertainties due to sampling become apparent if we notice e.g. that the Cu concentration varies in the proportion of 10 to 1; and that the Gd concentration in these groups of iron meteorites varies in the proportion 60 : 20 : 2. These difficulties are of the same order as those for the Earth, as may be expected if the meteoritic rocks have been formed by similar processes as the terrestrial ones. The results of Urey may probably be considered as the best information available on the composition of meteorites ; we have borrowed them from the paper by Suess and Urey (1955) and listed them in Table I.

The solar exterior.—The chemical composition of the solar photosphere is better known than that of any other celestial body. We know that convection currents are stirring the exterior layers to a depth of perhaps one-third of the radius; thus the composition of the photosphere is representative for about 0·7 (in volume) of the gaseous sphere. The flux of the radiation reaching the Earth is so strong that the spectrum can be obtained with a very great dispersion.

Moreover, we are able to study the influence of the photospheric structure by comparing the central parts of the disk to the limb. A measurement of a Fraunhofer line profile, or of its *equivalent width*, yields the abundance of the corresponding element, provided we know some *atomic constants* of the spectral line and the *stellar model*. Among the atomic constants needed, the oscillator strength (f-value) is the most important one, of which the knowledge is crucial for any abundance determination. The available values have been collected by Allen, Biermann, Garstang, Minnaert, Unsöld. About the important absolute f-values of iron there has been some uncertainty, but the results of Kopfermann and Wessel (1951) appear to be the right ones. For many of the elements occurring in the Sun, f-values are entirely lacking; in this case the only way is to make use of the sum rules, as was done by Russell in his pioneer investigation of 1929, which for these elements is still the only source of information. If we use only faint lines, the broadening effects in the photosphere have no influence but the measurements become more difficult. If stronger lines are used, we have to take account of the damping and we need data on the polarizability by hydrogen atoms, the theory of which may be wrong even by a factor of 5 (Weidemann, 1955); in rarer cases we also need the constants of the quadratic Stark effect and the hyperfine structure.

As to the stellar model, the first investigations on the composition of the Sun were based on the picture of a *homogeneous layer* at a certain temperature and pressure, in which the Fraunhofer lines are formed. The classical analysis of Russell and that of Unsöld (1948) were obtained in this way; the temperature and the electron pressure were derived from the Fraunhofer lines themselves and were found surprisingly consistent for the several elements. From the number of atoms contributing to the formation of the observed spectral lines, those in the other (non-observed) states of excitation and ionization are easily computed and the ratio between the fractional abundances is found, while their sum is put equal to one.

However, the real photosphere has a more complicated structure. Lines of high excitation and ionization are formed in deeper layers than lines of low *EP* and *IP*. In order to take into account such effects, we must first derive a *stratified model*, $T(\tau)$ and $P(\tau)$, which may be calculated, given the flux of radiation, the surface gravity and a rough knowledge of the chemical composition. We see that in principle a process of successive approximations will be necessary, by which alternately the abundances or the stellar model are determined, the method converging rapidly. Our knowledge of the stratified solar model has already reached a considerable perfection; the results derived empirically from the limb darkening and those obtained theoretically are almost consistent. Among the best models now accepted we mention these of Böhm, Böhm–Vitense, de Jager V, Peyturaux, Priester, Vitense II, Waddell and Pierce. In the integral $A=\mathscr{A}\int N(\tau).G(\tau).\psi(\tau)\,d\tau$, determining the equivalent width A, the weighting function $G(\tau)$ and the saturation function $\psi(\tau)$ are practically identical for all modern models and the differences between these relate mainly to the number $N(\tau)$ of effectively remaining absorbing atoms (Hubenet, 1957). General investigations concerning solar abundances on the basis of a stratified model were carried out by Claas (1951) and recently at the McMath–Hulbert Observatory by Goldberg, Aller and Müller (*A.J.*, **62**, 15, 1957); the improvement with respect to the homogeneous models refers especially to the abundances which are based

on medium strong lines and for which the curve of growth differs according to the depth where they originate. In several cases the abundances are decreased by factors of 2 or 3.

More searching investigations have recently proved that it is necessary to take into account the ***inhomogeneity of the photosphere***, and to develop a "two streams model" or a "three streams model" (Böhm, de Jager, Hubenet-de Jager, Voigt, Schröter). The photosphere is treated as if it were subdivided into vertical columns with effective temperatures T_1, T_2, (T_3), each having their particular function $P(\tau)$; the areas of the cross-section are put proportional to numbers a_1, a_2, (a_3), and the observed radiation is considered to be the sum of that of the individual columns. Since the number of atoms contributing to the formation of a line depends on the temperature and the pressure in a rather complicated way, the introduction of inhomogeneous models will modify the computed equivalent width by an amount which differs from line to line; or, conversely, will modify the abundances derived from measured equivalent widths. The effect will be the most pronounced for ion lines with high ionization and excitation potentials. In the Sun it does not seem very important. Modified abundances derived from inhomogeneous models were found by Voigt (1956) for oxygen and could have been deduced also for the other elements.

It should be noted that the role of the lower chromosphere in the formation of some spectral lines may not be neglected; however, it is not sure that the model of the lower chromospheric layers is sufficiently well known yet for this purpose.

Very recently, Pecker has found strong indications for deviations from thermic equilibrium in the higher photospheric layers, which differ from atom to atom and which would have rather important consequences for the abundance determinations.

In Table II we give:

(1) the results of a solar analysis derived from a homogeneous model by Unsöld (1948), improved for some elements by later work on stratified and inhomogeneous models; for all elements, except hydrogen, a correction of $-0{\cdot}28$ was applied, in agreement with the discussion by Weidemann (1955);

(2) the results of Claas (1951), based on a stratified model, the temperature of which, however, is considered nowadays as too high in the outer layers; according to Weidemann, an approximate correction of $-0{\cdot}28$ has been introduced; the results for Ti and Si, which were based on wrong f-values or on less suitable lines, have been dropped;

(3) the McMath-Hulbert results for the Sun.

A few comments have to be made on some elements of more exceptional behaviour.

The formation of the hydrogen lines is not completely understood. However, this hardly influences the abundance determinations, because the profile of a Fraunhofer line depends on the ratio between the selective and the continuous absorption, so that any metal line yields directly the ratio between the metal and the hydrogen abundances.

Helium lines are absent from the normal photospheric spectrum; the helium abundance should be derived from the chromosphere and the prominences. Unfortunately, the results of such an analysis depend so strongly on the temperature and on possible deviations from equilibrium, that no reliable

determinations have been reached yet (van de Hulst, 1953). The ratio He/H is found to vary from one prominence to another and from one part of a prominence to another; but this is probably an effect of varying electron pressure, self-absorption or excitation (discussion by Unsöld, 1955, p. 689). On Li, see Greenstein and Richardson (1951); on Be, see Greenstein and Tandberg-Hanssen (1953).

The abundances of C, N and O, determined from lines of high excitation, are rather uncertain; some results from molecular lines or from forbidden lines, mostly derived on the basis of homogeneous models, are mentioned in *Trans. I.A.U.*, 1948.

The element Technetium has not been found in the Sun (Greenstein and de Jager, 1956).

TABLE II

Abundances in the Sun

Element	Unsöld (1) (1948–1955)	Claas (1) (1951)	Goldberg, Müller, Aller (1957)
1 H	12·00	12·00	12·00
2 He	...	...	...
3 Li	...	0·80	0·86
4 Be	...	...	2·43
5 B	...	...	...
6 C	8·01	...	8·56
7 N	8·33	...	7·98
8 O	8·95 (2)	8·37	9·00
9 F	...	...	...
10 Ne	...	...	...
11 Na	6·08 (4)	6·05	6·30
12 Mg	7·23 (4)	7·29	7·28
13 Al	6·08 (4)	5·89	6·21
14 Si	7·26 (4)	...	7·60
15 P	...	...	5·44
16 S	6·64	...	7·17
17 Cl	...	...	...
18 A	...	...	...
19 K	4·92	4·73	4·96
20 Ca	6·12 (4)	6·18	6·38
21 Sc	3·05	...	3·20
22 Ti	4·68	...	4·96
23 V	3·77	...	4·03
24 Cr	5·30	...	6·00
25 Mn	5·18	...	5·30
26 Fe	6·91 (3)	6·81	6·76
27 Co	4·75	...	4·74
28 Ni	5·67	...	5·80
29 Cu	3·95	4·52	5·05
30 Zn	4·50	4·34	4·53

(1) All numbers of this author, except this for hydrogen, have been decreased by 0·28. See the discussion by Weidemann (1955).
(2) Modified according to Voigt (1956).
(3) Modified according to Kopfermann and Wessel (1951).
(4) Modified according to Weidemann (1955).

Stellar exteriors. (*a*) *Stars with normal spectra.*—Part of the general considerations which apply to the Sun are also valid for the stars. Here also the analysis was first made for a *homogeneous layer*. In early stars, the representative electron pressure was often determined from the widening of the Balmer lines or from the Balmer discontinuity, the temperature being derived from the ionization. We notice that abundances in different stars have often been compared by quoting the "number of atoms above the photosphere", without taking into account the differences in the effective thickness of the absorbing layer, the result being that *all* "abundances" are found to be less in one star than in another ! Such errors are, of course, avoided if *stratified models* are constructed. However, because the stellar disk is invisible, the radiation flux is not well known and the establishment of a model is more difficult than for the Sun. Here the purely theoretical method of the model atmospheres may be used with advantage : given a flux of radiation I, a surface gravitation g and a certain chemical composition, we compute a photospheric model and determine the energy wave-length curve, the Balmer jump and the equivalent widths of some important Fraunhofer lines. We then look for stars which show approximately the same characteristics and assume that our model applies to them. The abundances are calculated from the observed equivalent widths as was done for the Sun. An example of the application of a similar method on a large scale is found in the work of De Jager and Neven (1957 *a*). By this method the concept of "effective temperature" is avoided. Many times errors have been made because a wrong effective temperature was applied to one particular star.

TABLE III

Abundances in early stars

Element	10 Lac ; O9 V Traving (1957)	τ Sco ; B0 Traving (1955) Aller (1957)	ζ Per ; B1 I Cayrel (1957)	ϵ CMa; B2 II Aller (1956 *b*)	55 Cy; B3 Ia Aller (1956 *c*)	α Lyr ; A0 Hunger (1954)
H	12·00	12·00	12·00	12·00	12·00	12·00
He	11·23	11·23	11·31	11·70	11·18	10·84
C	8·37	8·37	8·26	8·36	8·41	...
N	8·37	8·57	8·31	8·73	8·63	...
O	8·77	9·12	9·03	8·98	...	8·87
Ne	8·72	9·72	8·61	...	...	...
Mg	8·22	7·73	7·77	8·50	...	7·70
Al	7·07	6·58	6·78	6·99	...	5·71
Si	7·75	7·63	7·97	7·71	7·46	7·24
Ca	...	...	...	...	...	6·20
P	...	...	...	5·91	...	...
S	...	...	7·48	7·55	...	...

Inhomogeneous models have not yet been introduced in the theory of stellar photospheres, except in the case of the Sun.

A very useful survey of 36 stellar spectra, analysed up to 1953, is found in the report of de Jager (1953 *b*). We quote the most important papers published since then. It will be seen that research has been concentrated primarily on stars of early type. From a methodical point of view, it is interesting to note that a "gross analysis", based on a homogeneous atmosphere, yields results which generally deviate but little from the "refined analysis" derived for a stratified atmosphere; the differences are of the order of 0·2 or 0·3 in log N. On the other

hand we see that more and more workers in this field are preferring the refined method, which undoubtedly gives a higher reliability and precision. The agreement between the results for the individual stars and for the Sun is satisfactory.

The discussion about the helium abundance started by de Jager, Neven and Miss Underhill seems decided in favour of Unsöld and his collaborators after the investigations of Traving (1955).

A number of other results have been obtained with medium dispersion: Mrs Hack has shown (1956 *b*) that these are valuable and that the differences between the abundances determined by several authors for the same star are not primarily due to the different dispersion used.

We mention a series of investigations of this type and quote some of the results for the light elements in early stars:

O-type	Mrs Hack (1956 *a*);
B-type	Righini *et al.* (1954); Mrs Hack (1954 *b*); Tempesti (1955);
A-type	Mrs Hack (1954 *a*);
F5-type	Mrs Hack (1956 *d*);
gK-type	Gratton (1954).

Element	O-type stars: Oke (1954 ; mean values)	O-type stars: Hack (1956 *a*)	B-type stars: Righini *et al.* (1954)	B-type stars: Hack (1954 *b*; mean values)
H	12·00	12·00	12·00	12·00
He	11·18	11·49	10·78	I 11·6; III 11·4; IV–V 11·0
C	...	8·07		
N	8·1	9·34		
O	7·7	9·59		

It is interesting to note the considerable differences occurring between the individual stars. Log He/H, as found by Righini *et al.*, varies between $-2\cdot22$ and $+0\cdot13$! A more detailed discussion would be useful; but the results already show that we must not content ourselves with a precise analysis of only one or two stars for each spectral type. The increased helium abundance in supergiants, found by Mrs Hack, confirms similar previous results of Unsöld (1944) and Voigt (1952), which, however, cannot be considered as definitely proved.

The results of Tempesti (1955) for the ratio He/H were obtained with a too small dispersion and seem less reliable.

The quantitative analysis of a stellar atmosphere was based by Oke (1954) on the difficult photometry of the emission lines. His results have been added for comparison in the above table.

Concerning the spectra of later types, only one recent investigation is to be mentioned, viz. the analysis of 14 red giants by Greenstein and Keenan (*Symposium Ann Arbor*, 1957).

A special investigation refers to ζ Aur, for which some abundances were determined by Groth (1955).

(*b*) *Stars with abnormal spectra.*—In cases where stars appear to have an abnormal spectrum, great caution is necessary: in the case of the spectrum variables, for example, we see how the spectral lines vary periodically, though

evidently there can be no real variation in composition. Many of the abnormalities described in the literature have been simply derived from the inspection of the spectrum without a complete quantitative analysis, and provisionally it is not proved that the chemical composition is peculiar. But even in those cases where the analysis has been carried out abnormal conditions of excitation, the influence of stratification, turbulence, selective fluorescence, rotation, magnetic fields, etc. may have been overlooked. In his concluding lecture at the Zürich symposium of the I.A.U. (1948), Struve expresses doubts concerning the reality of practically all discrepancies in the abundances, except in so far that the hydrogen abundance may be abnormal.

Since then, there has been a clear change in the general attitude. Considerations of nuclear processes inside the stars, and even at their surfaces, have made it understandable that the abundances may vary in the course of evolution, even for the heavier elements, and differences in chemical composition are now more readily accepted. These new possibilities have stimulated observational and experimental research ; we should, however, always realize that a complete exploration of all possible stellar models remains necessary before the new assumptions can be considered as *proved*.

Stars of population II.—The stars of which we call the composition normal are the stars of population I. With respect to these, characteristic differences are found in the stars of population II, which from a general point of view are very important. The following objects of this category have been recently analysed: high velocity K giants (Gratton, 1954 ; Schwarzschild *et al.*, 1957) ; high velocity F dwarfs (M. and B. Schwarzschild, 1950 ; Wellmann, 1955) ; A subdwarfs (Chamberlain and Aller, 1951 ; Burbidge, 1956) ; W Vir stars (Abt, 1954) ; globular cluster stars (Deutsch, 1955).

The lines of the metals and of cyanogen are in general abnormally faint, while those of CH are strong. These effects do not occur in the same way for all the population II objects ; it has become quite clear that in this respect there are many gradual transitions, the globular cluster stars being the most extreme type (Burbidge, 1956 *a* ; Schwarzschild *et al.*, 1957). The hydrogen lines are abnormally weak in subdwarfs and RR Lyrae stars, but strong in globular cluster stars, whereas all these stars clearly belong to population II and might be expected to show deviations in the same direction. Here is a clear example that the equivalent width of the lines of an element is not a simple measure of the abundance ! The observations seem understandable by assuming that there is an excess of hydrogen (see e.g. Schwarzschild *et al.*, 1951). In the publications quoted, elementary abundances have been systematically derived for the following objects:

High velocity stars, type dF : ratio C/Fe higher than normal (factor 2).

High velocity stars, type gK: ratio $\frac{\text{metals}}{\text{H}}$ smaller (factor $\frac{1}{4}$) ; ratio $\frac{\text{C, N, O}}{\text{H}}$ smaller (factor $\frac{1}{2}$).

Subdwarfs, type A : less Ca and Ba (factor 1–1/50), less iron (factor 1–1/10) with respect to the Sun ; de Jager (1953) suggests that the ratio $\frac{\text{met}}{\text{H}}$ has decreased (factor 1/10).

W Vir : $\frac{\text{Sr, Sc}}{\text{Fe}}$ smaller (factor 1/4).

It is very useful that de Jager and Neven (1957 *b*) have again investigated the equilibrium between the most abundant elements and the molecules which they form. They find that in giant stars of population II the observed weakening of CN and the simultaneous strengthening of CH correspond to a decrease of the ratio $\frac{\text{metals}}{\text{H}}$ (factor 1/15) and to a decrease of the ratio $\frac{\text{C, N, O}}{\text{H}}$ (factor 1/3).

No detailed differences have been found between the abundances of the individual metals in population I and in population II ; it seems that all metal abundances are affected by the same factor (Greenstein, *Symposium*, *Ann Arbor*, 1957).

A determination of the helium content in population II stars would be most interesting from the point of view of cosmogony; as yet, however, no information on this subject is available.

Hot subdwarfs. Very recently, Greenstein and Munch analysed the spectrum of HZ 44 and found quite abnormal abundances. The ratio He/H amounts to 2·3 and the ratio N/C to 250 ! (*Symposium*, *Ann Arbor*, 1957).

W-type stars.—As is well known, this group of stars is subdivided into a carbon sequence and a nitrogen sequence. The subdivision is not completely sharp, since Swings (1948) and Aller (1943) showed that in some WN stars strong carbon lines occur. A very rough estimate of the abundances in WR stars has been given by Aller (1943).

We quote here the values of *N* :

	WC	WN
He	50	89
C	3	0, 2
N		4
O	1	

Very recently, however, Miss Underhill tried to explain these two sequences as the effect of different excitation conditions on matter of one and the same composition.

As to the ratio He/H, there is a considerable disagreement between the earlier authors and the last results of Sljusarev (1955), who takes more account of the self-absorption and finds a ratio of 5 and 12 respectively for two W-type stars. It seems very important that the occurrence of such a surprising excess of helium be verified.

The nuclei of planetary nebulae are still imperfectly understood, no chemical analysis being possible as yet.

Abnormal O- and B-type stars.—Some stars have been found, belonging either to the late O-types, or to the B- or to the cA-types, which are distinguished by a very small amount of hydrogen compared with helium. In the O5 star HD 160641, and the B2 stars HD 124448 and HD 168746, there appears to be no hydrogen at all in the photosphere (Aller, 1954 ; Popper, 1947 ; Thackeray and Wesselink, 1952; Thackeray, 1954). There is very little of it in *v* Sag and HD 30353 (Bidelman, 1943 ; Greenstein and Adams, 1947). Even in these cases some doubt is possible; Unsöld (1948 *b*) notices that similar phenomena appear in the spectra of eruptive prominences, though these have a normal composition ; Bidelman draws attention to some RV Tauri stars and to U Mon, in which the hydrogen lines temporarily disappear ; Swings (1948) suggests excitation by a surrounding nebulous envelope.

Abnormal A-type stars.—About 13 per cent of these stars show abnormally strong or weak spectral lines and roughly 10 per cent of these " peculiar A stars " are conspicuously variable. For a general survey, see Deutsch (1956 *a*). Three of these stars have been carefully analysed by E. M. Burbidge and G. R. Burbidge (1955 *a*, 1955 *c*, 1956 *b*), and a programme of observations has been started by Casati and Hack (1956). Abnormally high abundances are found for the rare earths (by factors between 100 and 1000!) and for Mg, Si, Sr, Y, Zr, Mn, while Ca is deficient. Probably all peculiar A stars have a strong general magnetic field. If the spectrum is variable, the equivalent widths vary with the same period as the magnetic field ; the lines of the rare earths are periodically enhanced, especially Eu, next Gd II and Dy II ; the Cr I and Cr II lines vary in the opposite sense, while Si II and Mg II are about constant (e.g. α C Ven). In other such stars the variations are mostly confined to the rare earths or to ordinary elements such as Cr II.

Between maximum and minimum the number of active atoms may vary by a factor between 4 and 10 for the rare earths and by a factor 2 for the ordinary atoms. In HD 125248 the rare earths reach their maximum when the magnetic field is positive, in α C Vn their maximum coincides with a negative magnetic field (Babcock, 1951 and 1952).

It has been suggested that the lines of the rare earths, with their numerous components, are split up by the magnetic field and that the total equivalent width is thus increased. However, this could never explain the enormous overabundances which are found from the curve of growth. It seems probable that there is a certain localization of the elements and that some lines are mainly formed at one of the poles and others at the equator. Until these effects are better understood, conclusions about abnormal chemical composition must remain uncertain.

We note that a search for Americium in these stars has not been successful (G. R. and E. M. Burbidge, 1955 *b*).

Abnormal F-type stars.—The " metallic line stars ", formerly considered to be A-type stars with an excess of some metals, are now in general classified as F-type stars (FO–F) with deficiencies of some metals (Greenstein, 1948 and 1949 ; see also the discussion by Mustel and Galkin, 1955). Only 3 of these stars were analysed by means of the curves of growth from high dispersion spectra (Greenstein, 1948 and 1949) ; 7 others were investigated similarly by Mrs Hack (1956 *c*) from spectra with a medium dispersion. From a methodical point of view, it is interesting to compare the analysis of τ U Ma by Greenstein and that by Miczaika *et al.* (1956), based partly on the same material. The agreement is in general not unsatisfactory ; still, we notice that for Mg Greenstein derives a deficiency by 0·85 in log N, while Miczaika finds a superabundance by 0·2 (compared to the Sun) ; which means a discrepancy of a factor 10. The following elements seem to be distinctly anomalous :

Ca, Sc, Ti, Zr (deficiency) ; Na, Sr, Zn (excess).

Greenstein (*loc. cit.*) noticed that the deficient elements are those for which the second ionization potential has values between 12 and 16 eV, and suggested anomalous conditions of excitation by charge transfer, shock waves or other mechanisms.* Mustel and Galkin (*loc. cit.*) considered the possibility that for

* It is to be noted that the element *Y* **does** not conform to Greenstein's rules. Moreover, Deutsch (1956) did not find confirmation by studying metallic line stars in Coma and in Taurus.

these ions the continuous absorption coefficient decreases very slowly with increasing frequency. Neither of these assumptions seems to be confirmed. Rudkjöbing (1949) and Ch. Pecker (1953) tried to find another solution, by assuming that the " metallic line stars " would have a hydrogen convection zone *in radiative equilibrium*, this being due to an abnormally small helium abundance. Clearly there are many possibilities left for an explanation and it would be premature to assume a peculiar chemical composition.

*Abnormal Late-type stars.**—While M-type stars are considered as normal, there is a great variety of late-type stars with peculiar spectra, among which unfortunately not a single one has been quantitatively analysed. Two series are generally distinguished : in *C-stars* the ratio of carbon to oxygen is about 1 (Bouigue, 1954) whereas it is smaller in the *S-stars*. There appears to be gradual transitions between M, S, and C stars, which may be understood as a function of the C/O ratio. Small differences in this ratio already explain considerable variations in the C_2 bands.

The relative variations in the bands of TiO and ZrO are partly due to differences in temperature and pressure (Wurm, 1940), combined with small differences in the C/O ratio (de Jager and Neven, 1956). Many authors, however, are of opinion that real differences in the Zr abundance cannot be denied (Bouigue, 1956 ; Buscombe and Merrill, 1952). Moreover, the following spectral peculiarities are generally attributed to real differences in elementary composition :

(*a*) the appearance of lithium lines: it seems that there is a group of Li-rich and a group of Li-poor stars (McKellar and Stilwell, 1944 ; Feast, 1954) ;

(*b*) the strong technetium lines in S-type stars: Greenstein (1954) estimates that $Tc/Fe \simeq 5 \times 10^{-5}$ in R And, which would make the abundance of Tc more than 1000 times that of normal stars. Also, in this respect, a transition towards other late-type stars appears possible, since weak Tc lines have been discovered also in M- and C-type stars (Merrill, 1952 and 1956) ;

(*c*) the differences in the intensity of the CH bands, which are very strong in the " CH stars ", weaker in the " Ba II " stars, and very weak in the R CBr stars. This corresponds to variations in abundance of hydrogen and is directly related to the population type (see p. 324). Very interesting results on the composition of *T Tauri stars* have been reached recently by Herbig and Hunger (*Symposium, Ann Arbor*, 1957).

Stellar interiors.—It may be questioned how far the composition of the photosphere is representative for the interior of the stars. We know that convection extends over about 30 per cent of the radius in the Sun and in the red dwarfs (Osterbrock, 1953). In A-type stars the convective layer is much shallower, amounting only to a few thousand kilometers, but there we may expect that the rotation stirs the matter to the deep interior. On the other hand, there seems to be deep convection in N- and S-type stars (Cameron, 1955).

Evidently it would be of the greatest importance if the same stars that appear to have a peculiar composition at their surface were proved to have corresponding deviations in the interior. The methods of analysis are entirely different and a confirmation would be convincing. Such differences in internal composition may be found either from deviations from the mass-luminosity law or from the main Hertzsprung-Russell diagram.

* For a general review of the C- and S-stars and their abundances in these objects, see Bidelman (1953, 1956), Wurm (1956), Bouigue (1954, 1956).

Deviations from the M–L-relation occur, but most of these do not seem to be related to the abundance problem ; a few must be investigated more closely before a definite conclusion is possible (Struve, *Trans. I.A.U.*, 1948). It is rather unfortunate that for most of the stars with abnormal photospheric composition the masses are unknown, so that no test of their internal composition is possible.

Deviations from the main HR diagram have been explained almost entirely by differences in the hydrogen content X, and in the helium content Y, connected with the progress of their energy production. For the Sun the latest investigations of its internal composition yield a ratio $Z/X < 0{\cdot}04$, probably near to 0·01–0·02 ; while $Y/X = 0{\cdot}2$ to 0·3. This suggests that the internal composition is practically equal to that of the photosphere.

The internal constitution of the white dwarfs has been recently discussed by Schatzmann (1957). The spectra of these objects show a great variation. However, because of the high values of the gravity acceleration, an efficient sorting of the elements may be expected to have taken place, so that the spectrum is in no way representative of the interior, which must be practically deprived of hydrogen ; the transition layer between the dense core and the shallow superficial envelope of H, He, C, N, O has a thickness of only a few kilometres. Differences in spectrum may be explained by the varying amount of hydrogen left in the envelope, or by convection currents which, in some of these stars, convey metal gases into the surface layers. The two white dwarfs which do show helium lines, but no hydrogen lines, may be assumed to be entirely deprived of hydrogen.

Novae shells.—From an analysis of the spectra of six novae, Pottasch (personal communication) derived the following composition:

H	12	O	10·1	C	9 ?
He	11·2	N	10·1	S	8·4
		Ne	8·9		

The gaseous nebulae.—The composition of gaseous nebulae has been quantitatively investigated, especially by Menzel and by Aller, by spectrophotometry of the emission lines. The most recent summary is found in Aller (1957) and reproduced in Table I. As in the case of the Fraunhofer lines, we need a number of *atomic constants* and a *model* of the nebula. The atomic constants are the transition probabilities and the cross-sections for collision with rather slow electrons, which determine the excitation and emission of the several lines ; they have been calculated already for a great part by quantum mechanics. Although a nebula may be considered to be entirely transparent for the photographic wave-lengths, it is necessary to know its model, because the electron density of a gas homogeneously distributed will be entirely different from that of the same gas concentrated into filaments. From measures on Baade's photographs of the Helical Nebula, Menzel estimates that only 1/300 of the volume is filled with the luminous matter ; this, however, seems not to apply to all planetary nebulae. Seaton (1957) estimates that the regions with high electron density occupy 1 per cent of the total volume. Since emission lines are observed only for some of the ions present in the gaseous mixture, while the abundances of all other stages of ionization have to be computed from T and P_e, changes in the assumed density will considerably affect our results. Other uncertainties are introduced because of the differences between the volume of the

regions, emitting the individual lines. A really satisfactory analysis ought to be made of a nebula of approximately spherical symmetry, observed at individual points, starting from the centre outwards ; it would be a beautiful check if about the same composition was found over the whole nebula. As yet the abundances of helium and of nitrogen relative to hydrogen show considerable scatter from one nebula to another, but it is uncertain whether these differences are genuine ; Wurm (1954) showed that they depend systematically on the excitation of the nebula.

A recent discussion of the Orion Nebula yields an abundance ratio log He/H = 0·89 (J. S. Mathis, 1957). In this case the uncertainty about the electron pressure has but little effect on the results.

The interstellar medium.—Here also, a general picture of the distribution and the motions of interstellar matter is essential for the derivation of abundances. It is taken for granted that the gas is concentrated into clouds, in which there is thermal and turbulent motion, while the separate clouds have random velocities and share in the differential galactic rotation. In the H I regions the electron density and temperature are entirely different from those in the H II regions. Considerable uncertainty is introduced into the calculations because we do not know well the far ultraviolet radiation which produces the ionization. One of the best-studied regions is the dense cloud in front of χ^2 Orionis, in which abundances have been determined for H, Na, Ca, K, Ti. For the average clouds the observational material is much more scarce. In general the solar abundances seem to correspond to the observations, with only a few exceptions (Seaton, 1951 ; Strömgren, 1954). Very interesting is the deficiency of calcium and beryllium relative to sodium, found by many authors and recently confirmed by Strömgren (1948), Seaton (1951), Spitzer and Field (1955). Aluminium, which could be expected to have about the abundance of calcium and sodium, is not observed. This could be due to erroneous assumptions about the far ultraviolet radiation of the stars, which determines the ionization of each of the two elements (Seaton, 1951).

The solid grains, though constituting only 1 per cent of the mass of the gas, are certainly important for the chemical composition of the universe. Unfortunately, very little is known about their constitution ; Van de Hulst suggests :

100 molecules H_2O
30 molecules H_2
20 molecules CH_4
10 molecules NH_3
5 molecules MgH, etc.

Assuming this tentatively, and taking for the interstellar gas the same composition as for the Sun, we find :

	Gas	Dust
H	1 000 000	1500
O	16 000	8000
C	3000	1200

Apparently it could well be that the amounts of all elements except hydrogen and helium are of a comparable order in the dust and in the gas. The surprising deficiency of aluminium, calcium and beryllium with respect to sodium in the gas

could be explained if it were assumed that these elements are relatively more concentrated in the grains.

The cosmic radiation.—The incident particles of the primary cosmic radiation have been recorded by means of photographic emulsions, carried to great heights by pilot balloons. From the number of silver grains or from the number of secondary δ electrons per unit path-length, the atomic weight of the particle may be roughly derived. It is necessary to take into account the velocity of the particle, which may be deduced from the total path-length in the emulsion ; from the straggling ; or from the direction along which α particles are ejected if the particle collides with a proton of the emulsion. Especially difficult is the correction for the collision processes which take place in the uppermost layers of the atmosphere and which modify the elementary composition. The corrected statistics of the tracks show a general agreement with the abundances in stars ; the only exception concerns the group of the elements Li, Be, B, of which the total abundance was quoted by some authors as equal to the total abundance of C, N, O, F (Dainton *et al.* 1952 ; Gottstein, 1954 ; Singer, 1953), while others estimated the ratio to be below 0·1 (Bradt and Peters, 1950 ; Peters, 1952, the Minnesota group). It seems now more and more probable that the true value is near 0·35 (Hourd *et al.*, 1954 ; Kaplon *et al.* 1954 ; Webber, 1956). This information is especially important, because the presence or scarcity of these special elements may inform us about the origin of the primary radiation (cf. Gething, 1954 ; Ginsburg and Fradkin, 1956 ; etc.).

The following table gives mean values derived from the authors quoted and from Danielsen *et al.*, 1956 ; Davis *et al.*, 1956 ; Linsley, 1956).

Abundances in the cosmic radiation

H	12
He	11·4
Li, Be, B	10·0
C, N, O, F	10·5
at. number $Z > 10$	10·0

Vernov, Zatsepin and Fradkin (1954) even give separate values for Ne, Mg, Si, Fe and the sum of the elements with $30 < Z < 92$.

The isotopic constitution of the elements.—A real understanding of cosmical abundances must be based on a study of each nuclear species. In general the relative ratios of isotopes are much more reliable than those of the individual elements, because they have rarely been modified in the course of the evolution. In this respect we have to rely almost entirely on the Earth and the meteorites, of which the isotopic constitution seems almost the same ; we quote the book of Rankama, *Isotope Geology* (1954), and Ahrend's *Relative Abundance Charts of Isotopes* (London, 1956). Suess and Urey (1956) have given a complete list of isotopic abundances from the whole of the available information. An important general paper is also that of Ahrens (1957). Information on the isotopic constitution of other celestial bodies is scarce and has to be derived from the spectra; in many cases only maximum limits can be stated.

The question of the deuterium in the Sun is a very difficult one. The best chance to discover this isotope would be a search for the Dα-line, which however, may be expected to be very broad, shallow and merging into the wing of Hα. The last results of Kinman (1956) yield an upper limit $N_D/N_H < 4 \times 10^{-5}$,

considerably less than the terrestrial and meteoritic ratio $1 : 5 \times 10^{-4}$. In the Orion nebula, D/H seems to be less than 10^{-3} (Greenstein, 1954).

Radio observations may bring some information on the amount of deuterium in interstellar space. Getmansev and his collaborators (1956), observing in the direction of the galactic centre, have found evidence for the existence of the deuterium line at 91·6 cm in absorption. At first they estimated the deuterium abundance to be equal to 1/300 of the neutral hydrogen abundance. Afterwards Pikelner observed that in this calculation the hydrogen concentration N_H had been assumed to be of the order of one atom per cm^3, while it probably increases towards the galactic centre; in this case the relative deuterium abundance, derived from the measurements, might prove several times smaller than first stated. Stanley and Price (1956) repeated these observations but were not able to find an indication of the deuterium line; according to them, the amount of deuterium is in any case less than 40 per cent of the abundance found by Getmansev.

A search for He^3 in the Sun leads to a limiting value He^3/He^4 $<0·02$ (Greenstein, 1951); in the magnetic A star 21 Aql it may be of the order of unity (Burbidge, 1956*c*).

It is questionable whether Li^6 occurs in the Sun; in any case Li^6/Li^7 is less than 0·3 (Greenstein and Richardson, 1951).

The C^{13} isotope occurs on Earth and in meteorites, the ratio C^{12}/C^{13} being about 90. On the Sun, Righini (1956) found the remarkably high value C^{12}/C^{13} $= 10^4$. In comets C^{13} is never so abundant relative to C^{12} as in the N-type stars (Swings and Haser, 1956, p. 17). Very remarkable are observations of Swings and Bobrovnikoff, who noticed variations of the C^{12}/C^{13} ratio from one comet to another (Greenstein, 1954; Swings and Haser, *loc. cit*). These variations could be related to the difference in behaviour between homonuclear and heteronuclear molecules in comets; it would be in line with other observations, if the profiles of the C^{12}C^{13} bands varied with the distance to the Sun, while those of the C^{12}C^{12} bands remained constant.

In R-type stars, McKellar (1948) distinguishes two groups, one of 12 stars for which the C^{12}/C^{13} ratio is near 3·4, another of 3 stars for which it is higher than 50; one star yields an intermediate value. In N-type stars Shajn, partly in co-operation with Miss Hase, studied carefully the C^{12}C^{13} and C^{13}N^{14} bands and found great variations in the C^{12}/C^{13} ratio, the limits being 2 and 20, in excellent agreement with the results for R-type stars (Shajn and Hase, 1954).

According to Wyller (1957), the ratio C^{12}/C^{13} in RN stars varies from 0·26 to 3·66; however, this result might be modified if the influence of self-absorption could be better accounted for.

Extremely interesting is the correlation of the C^{13} abundance with the space velocity and the population type. Ordinary R-type stars are rich in C^{13}; while high velocity stars, or stars with strong CH or C$_2$ bands, have a ratio C^{12}/C^{13} of perhaps 100 (Bidelman, 1953*a*). It is remarkable that the terrestrial ratio coincides with that of population II stars!

In interstellar space, the ratio C^{12}/C^{13} exceeds 5 (Wilson, 1948).

A search for isotopes of titanium was made by Herbig (1948) in the spectra of late-type stars; none of the isotopes could be definitely detected, but abundance limits could be assigned.

The abnormally broad lines of Mn and other elements in the solar spectrum, due to hyperfine structure, show that the presence of isotopes may be detected, even if their lines cannot be resolved.

Table IV summarizes the information available on isotope ratios outside the Earth.

TABLE IV

Abundance of some isotopes

	Earth, meteors	Sun	Stars	Nebulae	Interstellar gas
H^2/H^1	1.5×10^{-4}	$<0.4\times10^{-4}$		<0.001	<0.001
He^3/He^4		<0.02	In 21 Aql : $\simeq 1(?)$		
Li^6/Li^7	0.077	<0.3			
C^{13}/C^{12}	0.011	10^{-4}	R stars : $\begin{cases} 0.3 \\ <0.02 \end{cases}$ N stars : $\begin{cases} 0.5 \\ 0.05 \end{cases}$ Population II : 0.01		<0.2
Ti^{46}/Ti^{48}	0.11		Ko–M6, S: <0.30 ; >0.04 ?		
Ti^{47}/Ti^{48}	0.11		Ko–M6, S: <0.30 ; >0.04		
Ti^{49}/Ti^{48}	0.075		Ko–M6, S: <0.3		
Ti^{50}/Ti^{48}	0.073		Ko–M6, S: <0.3		

Conclusion.—We shall now try to carry out our programme, as it was sketched in the introduction, and shall first discuss Table I. Our best information about cosmical abundances is based on the three central columns, which refer to the meteorites, the Sun and the early stars ; these are the abundances which we must compare in the first place and which we must try to combine. The agreement is in general satisfactory. The abundances of the gaseous elements are in general better determined in the early stars ; those for the metals are more reliable in the table for the Sun. The column for the meteorites, although very useful, remains less reliable in our opinion, since it is dubious in how far the chondrites are really representative of the whole of the meteoritic matter ; moreover, the abundances of this column had to be multiplied by a suitably chosen factor in order to make them comparable with those of the other columns. Data derived from the planetary nebulae are much less certain but are valuable for some special elements.

Strong discrepancies within the central columns are found for fluorine, phosphorus and sulphur ; but these are elements of which the abundances are determined only with the greatest difficulty and must be subject to considerable errors.

Real differences in composition are found for lithium, which is deficient in the Sun, and for H, He, C, N, O, Ne, and A, which are deficient in the meteorites for obvious reasons. Beryllium does not seem discrepant. If we leave aside the meteorites, the abnormal abundances which we have discussed concern (*a*) the elements H, He, Li, C, and N, which are directly concerned with the processes of energy production ; (*b*) the element technetium, which forms a problem by itself ; and (*c*) perhaps zirconium, the rare earths and some other metals.

As to the isotopic constitution, we find clear differences only for C^{13}/C^{12} and perhaps for He^3/He^4 ; remarkably enough, these are again elements which

are involved in the energy-producing cycles. However our present methods of investigation are insufficient for an isotopic exploration of the universe.

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The following abbreviations have been used :

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SOLAR ACTIVITY

Sunspots.—Solar activity continued to rise steeply during 1956 and the Zürich relative sunspot number for November (201·3) was as high as during any month of the preceding sunspot cycle. The yearly mean was 141·7, compared with 38·0 for 1955 and 92·6 for 1946, the corresponding year in the previous cycle.

After November the number of sunspots fell somewhat, and the peak of the solar cycle may possibly have been passed.

The number of sunspot groups with maximum areas exceeding 1000 millionths of the Sun's hemisphere was 24, against 2 in 1955. The largest group (central meridian passage, September 11·6 ; latitude 23° South) exceeded 2000 millionths but was not as great as many in the previous cycle. The high level of activity was occasioned mainly by the unprecedented frequency of medium-sized groups. The number of solar flares observed at Herstmonceux (excluding those of Class 1^-) was 117, rather more than in any previous similar period, and 8 times as many as in 1955. These included 39 of Class 2 and 7 of Class 3.

On February 23 at $03^h\ 45^m$ there was a sudden drop in the night-time level of atmospherics associated with disturbances, caused by an intense solar flare at 74° West heliographic longitude, which produced the largest increase of cosmic-ray intensity yet recorded at intermediate and high latitudes. It is

interesting to note that at Tokyo the flare was observed in white light as a bright spot. Compared with 1955, sudden enhancements of atmospherics (S.E.A's) on 27 kc/s increased by a factor of 5 and sudden ionospheric disturbances (S.I.D's) by a factor of 10.

There was also a considerable increase in terrestrial magnetic activity throughout the period.

P. S. LAURIE.

Prominences.—With the approach of the maximum of the solar cycle, prominence activity continued to be on the increase throughout 1956. The mean daily areas and numbers of calcium prominences at the limb as derived from photographs obtained at Kodaikanal were as follows:

1956	Area in square minutes North	South	East	West	Total	Number North	South	East	West	Total
Jan.–June	3·92	1·85	3·22	2·55	5·77	5·39	3·87	4·49	4·77	9·26
July–Dec.	3·40	2·85	3·41	2·84	6·25	5·17	4·71	4·85	5·03	9·88
Whole year (weighted mean)	3·71	2·26	3·31	2·66	5·97	5·31	4·21	4·64	4·88	9·52

Compared with the previous year, prominence activity as represented by areas increased by 60 per cent while the increase was 21 per cent as judged by numbers.

In the northern hemisphere the distribution of areas in five-degree ranges of latitude showed a maximum at 55°–60° with a secondary maximum at 30°-35°. Compared to the previous year the zone of activity had thus advanced by about 15 degrees towards the pole. The maximum activity in the southern hemisphere was at 45°–50° with a less pronounced secondary maximum at 5°-10°. On the whole, activity was considerably less in the southern hemisphere than in the northern. There was an eastern preponderance in prominence areas, but the numbers showed a slight western excess.

Three metallic prominences were observed during the year.

Doppler shifts of the H-alpha line in prominences and absorption markings observed with the prominence spectroscope and the spectrohelioscope are summarized below:

	North	South	East	West	To red	To violet	Both ways	Total
Prominences	142	102	138	106	4	...	240	244
Dark markings	22	13	21	14	2	1	32	35

The heights of 55 fairly tall prominences were measured in H-alpha, D_3 and H-Beta lines with the prominence spectroscope. These were compared with the corresponding heights in the K line as obtained from the spectroheliograms. The average heights were:

K	H-alpha	D_3	H-beta
70″·5	58″·5	50″·3	46″·2

26 instances of sudden disappearance of disk absorption markings and limb prominences were observed during the year.

The mean daily areas and numbers of hydrogen absorption markings on the disk as obtained from Kodaikanal records are given in the following table :

1956	Area in millionths of the Sun's visible hemisphere (uncorrected for foreshortening) North	South	East	West	Total	Number North	South	East	West	Total
Jan.–June	2744	1846	2355	2235	4590	17·67	11·56	14·96	14·27	29·23
July–Dec.	3046	2175	2544	2677	5221	17·82	13·49	15·63	15·68	31·31
Whole year (weighted mean)	2882	1997	2442	2437	4879	17·74	12·43	15·26	14·91	30·17

Compared with the previous year there was in 1956 a considerable increase in activity as judged from the areas as well as the numbers of hydrogen absorption markings, the increase in areas being 169 per cent and that in numbers 160 per cent. The noteworthy feature of the distribution of areas in latitude in the northern hemisphere was a pronounced peak of activity in the 25°–30° zone with a clear secondary maximum at 60°–65°. In the southern hemisphere too there were two peaks of activity, one in the latitude belt 30°–35° and the other at 45°–50°. The activity as judged from hydrogen absorption markings was however less in the southern than in the northern hemisphere, as was also indicated by the limb prominences. A. K. DAS.

COMETS (1956)

In 1956 nineteen comets were under observation, including three new ones and five periodic comets, as well as the two annual comets and nine of those mentioned in previous reports.

Comet Schwassmann–Wachmann (1) continued to show large fluctuations in brightness and appearance. Although at a low altitude, it was recorded by Van Biesbroeck at Yerkes in May as a very faint nebulosity, which on July 14 had assumed a stellar appearance. On August 3 at Lick, Jeffers noted the appearance of a round coma 2′ in diameter, in which the 17th magnitude nucleus was displaced from the centre. The coma was seen to be 5′ in diameter on August 7 but the nucleus had again become prominent by September 3 (Van Biesbroeck) when the total magnitude was estimated at 15. By October the appearance of the comet had again returned to normal.

Comet Oterma was recorded by Jeffers at Lick in August and October and by Miss Roemer at Yerkes on October 3. The nearly stellar image had a magnitude around 18.

1954 e, periodic comet Faye, was last observed on March 16 at Lick, as recorded in the last report. (*Observations* 1954 *July* 25 *to* 1956 *March* 16)

1954 g, periodic comet Schwassmann–Wachmann (2), was observed by Miss Roemer with the Crossley reflector at Lick on May 16 and 29, a year after previous observations and nearly fifteen months after perihelion passage. The comet was exactly on the ephemeris position and showed a nearly stellar image of magnitude 19. (*Observations* 1954 *July* 28 *to* 1956 *May* 29)

1954 h, Baade, continued to show considerable activity in the early part of the year. On February 2, Miss Roemer at Lick reported a well-condensed nucleus in a faint coma ; on long exposures, the nucleus was stellar, of magnitude 16·5,

placed unsymmetrically in the coma, with a jet extending 0′·5 in p.a. 170° and a broad tail 5′ long at 20°. On March 12, in poor seeing, a similar appearance was still obtained, and was confirmed by van Biesbroeck on the following night. The total magnitude was given as 12·5 on January 3 (Reinmuth, Heidelberg) while Beyer's observations (Hamburg-Bergedorf) showed a decrease from 12·3 on January 2 to 13·4 on April 7.

After conjunction with the Sun, the comet was again observed in the autumn at Yerkes, Van Biesbroeck describing the coma as very diffuse on September 11, while Miss Roemer gives it as moderately condensed on October 5 ; in both cases the magnitude was estimated at 17. The comet was still under observation in the new year. (*Observations* 1954 *July* 31 *to* 1956 *December, continuing*)

1954 k, Haro-Chavira, was a circumpolar object in the spring months, and has been observed continuously during the year. At Lick in February and March the comet was estimated at magnitude 14 and had a sharply defined nucleus about two magnitudes fainter. On April 1, Van Biesbroeck reported a short tail, which was still apparent in August (Yerkes, Lick) although the comet had by then faded to magnitude 15·5. The tail was only suspected in September, although the well defined nucleus remained easy to measure. On October 24, Miss Roemer at Yerkes reported a short tail 3′ long at 0°, but by December 30 Van Biesbroeck found only a round coma 25″ diameter, centrally condensed. The comet continues under observation, but is now fading. (*Observations* 1954 *December* 17 *to* 1956 *December, continuing*)

1955 b, Abell, was observed at Lick during the early months of the year. On February 15 it appeared as a diffuse coma of magnitude 18 and diameter 0′·1 with a faint tail in p.a. 80°. A similar but fainter image was obtained on March 20, while on April 30 a moderately sharp nucleus, magnitude 19·3, was observed, with a faint tail 0′·8 long at 80°. The comet was not found on June 2, and must then have been much fainter than magnitude 19. (*Observations* 1955 *April* 13 *to* 1956 *April* 30)

1955 c, periodic comet Ashbrook-Jackson was again observed in the summer when it had moved out into the morning sky. All reports agree that the object was fainter than the ephemeris predictions and from August to December it remained at about magnitude 17. In October it showed a nearly stellar nucleus (Roemer, Jeffers) with a short faint tail extending south-west. On December 22 (Jeffers) it showed only a small round diffuse image of magnitude 17·5. (*Observations* 1955 *April* 24 *to* 1956 *December* 22)

1955 d, Whipple, was photographed in January (Lick) and February (Yerkes) as recorded in last year's report. (*Observations* 1955 *May* 25 *to* 1956 *February* 6)

1955 e, Mrkos, was photographed at Lick on April 17, the 30-min exposure showing a condensed image of magnitude 17·5. (*Observations* 1955 *June* 12 *to* 1956 *April* 17)

1955 i, periodic comet Perrine-Mrkos, was last photographed in the first week of Feburary with the 20-inch at Lick, but the images could not be measured. (*Observations* 1955 *October* 19 *to* 1956 *February*)

1956 a was the periodic comet Olbers, whose return had been predicted by Rasmusen. It was recovered photographically on January 4 by Antonin Mrkos with the 50-cm reflector of his private observatory at Lomnický Stít; the image was described as diffuse, without central condensation, magnitude 16. The comet was thus less bright than had been expected, and this accounts for the failure of previous searches to locate it. Rasmusen's work was based on a complete revision of the motion of the comet since its discovery in 1815, and it was found that a close approach to Jupiter in 1888–9 had reduced the period from 72 to 69 years. Comet Olbers was recovered within $\frac{3}{4}°$ of the predicted position and subsequent observations indicated a correction of $+5{\cdot}5$ days to the time of perihelion passage. Pre-recovery positions were subsequently found on a plate taken with the 82-inch at McDonald on November 12 and on a Tokyo plate of January 2.

Miss Roemer, at Lick, described the comet on February 4 as having a sharp nucleus of magnitude 16·3 with a fainter coma $0'{\cdot}4$ in diameter. By the end of April the magnitude had reached 14·3 and the coma was somewhat larger. On March 31, Van Biesbroeck at Yerkes reported a condensed coma $4'$ diameter with an extension in p.a. $85°$ forming a coarse tail about $5'$ long, the total magnitude being 9·8. The tail is also reported in a long series of observations by Beyer covering the period March 28 to September 25, and it is clear that the comet became rapidly brighter in the summer. In June–July the total magnitude was less than 7, and during this period a coarse tail could be traced to $1°$ from the nucleus (Van Biesbroeck). The tail was still visible in early September, but was not mentioned in this observer's report on September 12 (magnitude 9·3) and was not seen by Beyer on September 25. Further observations should be possible in the morning sky in the spring of 1957. (*Observations January* 4 *to September* 25)

1956 b was the first new comet of the year, and was found visually on March 12 by Antonin Mrkos in the course of a routine search with 25×100 Somet-Binar binoculars. The comet moved rapidly north east and observers found it difficult to trace in the first few days after discovery. Van Biesbroeck found it the following day far from the centre of a plate taken with the Ross 3-inch lens, as a diffuse coma $3'$ diameter, magnitude 9. On March 21 its magnitude was 8·3, and a faint narrow tail $5'$ long was noted. Beyer made the magnitude somewhat brighter and also mentions the tail. By April 10 the magnitude (Yerkes) had dropped to 11, and this rapid decrease of brightness at the approach to perihelion is noted also in the report by Beyer, who gives a magnitude of 8·8 on March 28 (when $r=0{\cdot}892$) and of 10·4 on April 12 ($r=0{\cdot}842$).

The comet was last photographed on April 28 at Lick when the image was diffuse and difficult to measure, estimated magnitude about 17·5. A search with the 82-inch reflector at McDonald in early May failed to locate the comet. (*Observations March* 12 *to April* 28)

1956 c was discovered by C. A. Wirtanen on a plate taken on March 16 with the Lick 20-inch astrographic telescope and confirmed in the same way two days later. The comet was described as diffuse, with central condensation, magnitude 15·5, and a short faint tail was detected. Miss Roemer, using the Crossley reflector, obtained a number of photographs from March 20 to May 28.

Elements of

Ref.	Comet	T(U.T.)	q	e
(1)	1925 III Reid	1925 July 29·8551	1·633208	0·995069
(2)	1939 III Jurlof–Ach.–Hassel	1939 April 10·1689*E*	0·528266	0·998482
(3)	1939 V P/Pons–Winnecke	1939 June 22·7216	1·101472	0·669682
(4)	1942 VII P/Oterma	1942 Aug. 21·6942	3·389728	0·144364
(5)	1948 IX P/Ashbrook–Jackson	1948 Oct. 4·7793*E*	2·311016	0·395537
(6)	1950 VII P/Arend–Rigaux	1950 Dec. 18·9235	1·386497	0·610388
(7)	1951 VI P/Pons–Winnecke	1951 Sept. 8·6114	1·160607	0·653246
(8)	1952 II P/Harrington	1952 Feb. 6·6825	1·599159	0·540813
(9)	1952 IV P/Grigg–Skjellerup	1952 Mar. 11·1414	0·855697	0·703573
(10)	1953 b P/Brooks (2)	1953 Aug. 7·3616	1·866111	0·486654
(11)	1953 f P/Encke	1954 July 2·5200	0·338403	0·847302
(12)	1955 e Mrkos	1955 June 4·1864	0·534786	0·990452
(13)	1954 k Haro Chavira	1956 Jan. 26·9612	4·07392	1·0
(14)	1956 b Mrkos	1956 April 13·6089	0·842360	1·0
(15)		1056 April 13·613	0·8422	1·0
(16)	1956 a P/Olbers	1956 June 15·867*p*	1·178530	0·930327
(17)	1956 f P/Johnson	1956 July 24·219*p*	2·25878	0·375060
(18)	1956 g P/Crommelin	1956 Oct. 19·369*p*	0·743220	0·919153
(19)	1956 i P/Grigg–Skjellerup	1957 Feb. 2·743*p*	0·855362	0·703635
(20)	1956 e P/Tempel (2)	1957 Feb. 4·949*p*	1·369473	0·547576
(21)	1956 h Arend–Roland	1957 April 8·1063*E*	0·316679	1·000178
(22)		1957 April 8·0462	0·316162	1·000204
(23)	1956 c Wirtanen	1957 Aug. 31·2855	4·450686	1·0

References and Notes to Table of Elements

(1) 1925 III Reid. Stefan Wierzbiński, *J. des Obs.*, **39**, No. 7, p. 124, 1956. This is a correction of the orbit given in *M.N.* **114**, and *UAIC* 1432.

(2) 1939 IV Jurlof–Achmarov–Hassel. L. Belous, *Ast. Circ. U.S.S.R.* No. 168. Definitive, 358 observations in 12 normals covering a 39 day arc ; perturbations Venus to Saturn.

(3) 1939 V Pons–Winnecke. V. L. Ananjeva, *Pub. Ast. Obs. Kasan*, No. 32. From two apparitions 1933–1939 with perturbations by planets Venus to Saturn.

(4) P/Oterma. A. Fokin, Unpublished dissertation. Elements from 7 apparitions 1943–1950 with Jupiter and Saturn perturbations ; 100 observations in 7 normals.

(5) 1948 IX P/Ashbrook–Jackson. M. Merslyakova, Unpublished dissertation. 92 observations, 14 months arc, with perturbations by planets Mercury to Saturn.

(6) 1950 VII P/Arend Rigaux. I. Hasegawa, *UAIC* 1566. 39 observations, January 8 to April 5. Gives predicted orbit for 1957.

(7) 1951 VI P/Pons–Winnecke. M. P. Candy and J. G. Porter, *B.A.A. Handbook* 1957. Elements of *M.N.* **112**, 342–3, 1952, corrected by 7 observations 1951 Feb.–Oct., with prediction for 1957.

(8) 1952 II P/Harrington. K. Hurukawa, *N.A.Z.* **10**, 28, 1956. Corrected elements using observations 1951 Oct. 8 to 1952 Apr. 24. A prediction for 1958 is given.

(9) 1952 IV P/Grigg–Skjellerup. C. Dinwoodie, *B.A.A. Handbook* 1957. Elements of *M.N.* **113**, 390–1, 1953 corrected by 5 observations in 1952.

(10) 1953 b P/Brooks (2). A. Dubiago, *Ast. Circ. U.S.S.R.* 168. See also reference given below.

(11) 1953 f P/Encke. G. Makower, *UAIC* 1595. From observations during 5 apparitions, 1937–1954, with perturbations by planets Mercury to Saturn.

(12) 1955 e Mrkos. I. Hasegawa, *UAIC* 1551. 5 normals, 81 observations, covering a 44 day arc ; residuals reach 11″ in one case.

Cometary Orbits

Period (years)	ω	☊	*i*	Equinox	Epoch of Osculation	Ref.
	°	°	°			
...	259·2719	5·9892	26·9724	1925·0	...	(1)
6490	89·2480	311·4312	138·1153	1939·0	1939 May 2·0 E.T.	(2)
6·09	169·3489	96·7978	20·1228	1950·0	1939 June 26·0 U.T.	(3)
7·89	354·7883	155·1680	3·9898	1950·0	1943 Oct. 3·0 U.T.	(4)
7·48	348·9042	2·3412	12·5132	1950·0	1948 Sept. 6·0 E.T.	(5)
6·71	326·2713	124·7280	17·1897	1951·0	...	(6)
6·12	170·2266	94·4012	21·6809	1950·0	1951 Aug. 22·0 U.T.	(7)
6·50	186·9033	254·2753	18·4945	1950·0	...	(8)
4·90	356·3294	215·4232	17·6349	1950·0	1952 Mar. 9·0 U.T.	(9)
6·92	195·6918	177·6806	5·5509	1950·0	1953 Aug. 11·0 U.T.	(10)
3·30	185·1991	334·7460	12·3740	1950·0	1954 May 18·0 U.T.	(11)
419·19	32·5590	48·3096	86·4828	1955·0	...	(12)
...	57·3332	72·2549	79·6251	1955·0	...	(13)
...	80·9111	226·0083	147·3481	1956·0	...	(14)
...	81·017	226·117	147·450	1956·0	...	(15)
69·569	64·6362	85·4153	44·6099	1950·0	1956 June 16·0 U.T.	(16)
6·87	205·8998	118·1735	13·8602	1950·0	...	(17)
27·87	196·0472	250·3651	28·8697	1950·0	1956 Oct. 14·0 U.T.	(18)
4·90	356·2974	215·4281	17·6431	1950·0	1957 Jan. 2·0 U.T.	(19)
5·27	191·0129	119·2780	12·4701	1950·0	1957 Feb. 11·0 U.T.	(20)
...	308·7430	215·1454	119·9884	1950·0	...	(21)
...	309·7760	215·1562	119·9615	1950·0	...	(22)
...	12·8833	233·2072	33·1036	1956·0	...	(23)

(13) 1954 k Haro–Chavira. G. Merton, *UAIC* 1542. 4 pairs of observations Jan. to Sept. 1955. Residuals average 7″ for 2 middle places.

(14) 1956 b Mrkos. G. Schrutka-Rechtenstamm, *UAIC* 1549. No details.

(15) E. Roemer and A. Mowbray—*ibid.* No details.

(16) 1956 a P/Olbers. H. Q. Rasmusen, *Pub. Cop. Obs.* No. 147, 20. Predicted elements based on those of 1815 and 1887 ; 24 normals with perturbations by all planets. Observations indicate $\Delta T = +5{\cdot}35$ days.

(17) 1956 f P/Johnson. W. H. Julian and B. O. Wheel, *B.A.A. Handbook* 1956. Observations indicate $\Delta T = +2{\cdot}4$ days.

(18) 1956 g P/Crommelin. M. P. Candy and J. G. Porter, *B.A.A. Handbook* 1956. Predicted elements based on those of *M.N.* **116**, 226–7, Ref. (1). Observations indicate $\Delta T = +5{\cdot}86$ days.

(19) 1956 i P/Grigg–Skjellerup. C. Dinwoodie, *UAIC* 1562 and *B.A.A. Handbook* 1957. Prediction derived from elements of Reference 9 above. Observations indicate $\Delta T = -0{\cdot}15$ days.

(20) 1956 e P/Tempel (2). R. Luss, *B.A.A. Handbook* 1956. Prediction based on the elements of *M.N.* **112**, 243–3, 1953. These were corrected for observations before applying perturbations by Jupiter and Saturn. Observations indicate $\Delta T = +0{\cdot}1$ day.

(21) 1956 h Arend–Roland. M. P. Candy, *UAIC* 1585. 76 observations arranged in 6 normals covering 1956 Nov. 7–1957 Jan. 26.

(22) 1956 h Arend–Roland. J. Kovalevsky, *UAIC* 1591. 48 observations, 1956 Nov. 18 to 1957 Jan 23. The discrepency of 1° in ω between these two orbits needs investigation.

(23) 1956 c Wirtanen. E. Roemer and A. G. Mowbray, *UAIC* 1555. Based on 3 observations March 20, April 2, April 30.

The appearance of the comet remained almost unchanged, with a nucleus of magnitude 16·5 surrounded by a slightly unsymmetrical coma about 20″ diameter and with a faint persistent tail in p.a. 300°. A similar description is given from Yerkes by Van Biesbroeck who last saw the comet on June 2 before its conjunction with the Sun.

The comet was nearly 5 a.u. from the Earth at the time of discovery, and will not reach perihelion (with a large perihelion distance of 4·5) until August 1957. (*Observations March* 16 *to June* 2)

1956 d was reported by Martynov (Engelhardt) as having been discovered by Tcherepashtshuk, but this object has not been confirmed.

1956 e, periodic comet Tempel (2), was recovered by Van Biesbroeck using the 82-inch reflector at McDonald Observatory on May 5. The comet, of magnitude 19, was exactly in the place predicted by R. Luss in the *B.A.A. Handbook*, but it is badly placed for observation and no other reports have been received. (*Observed May* 5)

1956 f, was the second apparition of periodic comet Johnson 1949 II. It was recovered by J. A. Bruwer at Johannesburg, using the Franklin Adams astrographic telescope of the Union Observatory, on August 6. The magnitude of the comet was then 13·5, which is close to the limit for the F.A. camera, and the comet was followed at Johannesburg only until September 12. It was recorded at Yerkes by Van Biesbroeck on September 3 and 8 as a fairly well defined coma about 20″ diameter; the magnitude was estimated at not brighter than magnitude 15, but the object was then at low altitude.

Miss Roemer photographed the comet at Yerkes on September 28 and October 1, and again on October 28, by which time the magnitude had become 17·8 and the image appeared as a weak diffuse spot about 0′·4 diameter on 20-minute exposures. (*Observations August* 6 *to October* 28)

1956 g, periodic comet Crommelin, was recovered on September 29 by Mrs. Ludmilla Mrkosová-Pajdušáková at Skalnaté Pleso Observatory during a visual search with the 25 × 100 Somet–Binar binoculars. The comet was then of magnitude 10, and in view of the prolonged searches which had been made at many observatories, must be regarded as much fainter than was expected.

The early observations indicated a correction of $+5\frac{1}{2}$ days to the predicted time of perihelion. The prediction was based on a correction of the 1928 orbit using the few observations available. The comet has been a diffuse object at previous returns and accurate observations rare. On this occasion the nucleus appears well condensed, and it is to be hoped that the observations secured at this apparition may enable an improved orbit to be computed.

Miss Roemer found the comet conspicuous visually in the 24-inch reflector at Yerkes on October 3. Photographs showed a well condensed centre to a coma nearly 1′·5 in diameter, with a suggestion of a very narrow tail extending about 3′ in p.a. 300°. Similar appearances were given by plates taken on other nights during the month ; in all cases the nucleus, of about magnitude 14, was surrounded by an unsymmetrical coma.

The comet was also photographed at Johannesburg on November 7, magnitude 7·3, and at Cordoba on November 10. The last observation reported comes from Bosque Alegre on November 29. (*Observations September* 29 *to November* 29)

1956 h, Arend–Roland, was found on two 30 × 30 cm Kodak 103 aO plates taken with the twin astrograph at Uccle on November 8 during routine observations of asteroids. The comet was then a tenth magnitude object, but the first reliable orbits showed promise of a considerable increase in brightness as the comet approached perihelion in 1957 April. Observations by Beyer at Hamburg-Bergedorf and by Jeffers at Lick showed a progressive brightening by 1^m by the end of 1956, while Van Biesbroeck at Yerkes on December 27 noted a short tail 8′ long in p.a. 51°. The more accurate orbits computed from the many observations that became available showed that the motion is definitely hyperbolic. (*Observations November* 8 *to end of year, continuing*)

1956 i, periodic comet Grigg–Skjellerup, was recovered on December 29 by K. Tomita at Tokyo, estimated magnitude 14. It was observed by Van Biesbroeck at low altitude on December 30 and again in the early days of January by Tomita, but the object was diffuse and measurements uncertain. No other information is available. (*Observations December* 29, *continuing*)

Unsuccessful searches were made during the year at Yerkes, Lick and Johannesburg for periodic comet Schajn–Shaldach ; negative reports were also received of periodic comets d'Arrest (Yerkes and Lick) and Taylor (Yerkes), and of comets 1955 f, 1955 g and 1955 i (Lick).

The numerical designation of comets (in order of perihelion passage) has been extended by the I.A.U. Bureau (*UAIC* 1580). The list that follows continues that given in *M.N.* **116,** 225, 1956. The perihelion dates (T) are from orbits noted in these annual reports.

Comet	T		Name	Year and letter
1953 I	Jan.	5·4	Harrington	1952 e
II	Jan.	24·9	Mrkos	1952 f
III	May	26·4	Mrkos-Honda	1953 a
IV	June	8·7	P/Borrelly	1954 b
V	Aug.	7·3	P/Brooks (2)	1953 b
VI	Sept.	22·4	P/Harrington	1953 e
VII	Dec.	25·9	P/Finlay	1953 i

The table giving the elements of cometary orbits is arranged as in last year's report. Comets are listed in order of perihelion date, which is normally given in U.T. ; the symbol E indicates that the computer has used Ephemeris Time. A periodic comet is denoted by the symbol $P/$, and predicted elements by p after the perihelion date. Notes on each comet follow the table.

Additional Notes

Individual Comets

P/Halley. M. Kamienski, " Halley's Comet in 2320 B.C." *Acta Astr.*, **6,** (1) 3, 1956.

P/Wolf (1). M. Kamienski, *Acta Astr.* **6,** (2), 74 and **6,** (4), 153, 1956.

P/Encke. S. K. Vsessviatsky " On the change of brightness of Comet Encke–Backlund ", *Pub. Kiev. Obs.* (7), 31, 1956. S. G. Makower, *Trans. Inst. Theor. Astr.* VI, 67, 1956. The mass of Mercury is found ($1/m = 628000 \pm 350000$) from observations of Encke's comet in 1937–1954.

1949 VI P/Schajn–Shaldach. A. Dubiago, *A. J.* (*U.S.S.R.*), **33,** 382. Definitive elements (see *M.N.* **116,** 226, 1956) and prediction for 1957 using Ephemeris Time. A German abstract is given.

P/Brooks (2). A Dubiago, *Bull. Engelhardt Obs.* (*Kazan*) No. 32, 3, 1956. Definitive elements for the apparitions of 1925–1953. The elements freed from perturbations are not constant, suggesting rotation of the nucleus in the retrograde sense about an axis inclined at 33° to the orbit plane. Predicted elements for 1960 are also given.

P/Kopff. F. Kepinski, *Acta Astr.*, **6**, (4), 194, 1956. Ephemeris for 1956–7, but no elements.

1944 IV Van Gent. A. Przybylski, *Acta Astr.* **6**, (3), 117. Definitive orbit, later than that given in *M.N.* **114**, 368, 1954. An editorial note calls attention to a difference of opinion over the application of the aberration correction.

Predicted elements of periodic comets are given annually in the *B.A.A. Handbook*, and the following are also available:

P/Schwassmann–Wachmann (3)	T=1957 Oct. 12	*Ast. Circ.* (*U.S.S.R.*) 177.
P/du Toit–Neujmin–Delporte	T=1958 Aug. 8	To appear in *UAIC*.
P/Schajn–Shaldach	T=1957 Mar. 17	See ref. above.
P/Harrington (1), 1952 II	T=1958 Aug. 12	*N.A.Z.* **10**, 28, 1956.
P/Brooks (2)	T=1960 June 17	See ref. above.
P/du Toit (1)	T=1959 April 10	J. Bobone, *Cont. Cordoba* **1**, 9, 1955.

General

C. Hoffmeister. "Photographische Aufnahmen von Kometen", *Veroff. Sternw. Sonneborg*, Bd. 4, Heft 1, 1956. An excellent collection of cometary photographs.

S. K. Vsessviatsky. "Catalogue of absolute magnitudes of comets". *A.J.* (*U.S.S.R.*), **33**, (4), 516, 1956. See also various notes by the same author in *Ast. Circ.* (*U.S.S.R.*), 171.

Many papers of theoretical interest are to be found in Russian publications, notably *A. J.* (*U.S.S.R.*), **33**, 1956; *Bull. Inst. Theor. Ast.*, Tome 6, and in the *Ast. Circs.* (*U.S.S.R.*), 168, 169, 171, 173. See also *Publ. Kiev. Obs.* No. 7, 1956, "Questions of Cosmogony" (*U.S.S.R. Academy of Sciences*) Tome IV, *Publ. Ac. Sci. Latvian S.S.R.* (*Riga*), Vol. 6., and *Bull. Stalinabad Obs.*, No. 15.

J. G. PORTER.

THE PRESIDENT'S ADDRESS ON THE AWARD OF THE GOLD MEDAL TO PROFESSOR ALBRECHT UNSÖLD

Professor Sir Harold Jeffreys

The Gold Medal of the Society for 1956 has been awarded by Council to Albrecht Unsöld, Professor of Theoretical Physics at the Kiel University, for his work on the physics of stellar atmospheres.

Unsöld's first work appeared in 1927 when he was twenty-two years of age and since that time he has never ceased to press on with the application of physics to the outer layers of the Sun and stars. Indeed, he has left no stone unturned to ensure that everything known in physics, astronomy, mathematics, or any border-line subject, that can possibly contribute to our understanding of stellar atmospheres, is studied, assembled, and coordinated for that purpose.

To say that Unsöld is the leader in this field of work is something of an understatement. He leads by the importance of his contributions but he also shoulders a personal responsibility for the systematic progress of the whole subject. This he does through his book "Physik der Sternatmosphären". The appearance of this book in 1938 put into the hands of astronomers an authoritative but readable account of solar and stellar atmospheres in which there was a pleasantly intimate relation between theory and observation. Many

astronomers were then able to appreciate for the first time the quantitative significance of the spectroscopic information that was rapidly accumulating. The seventeen years that elapsed before the appearance of the second edition of " Sternatmosphären " saw a very great increase in the complication of the problems involved and the variety of contributing observations. Nevertheless our medallist has kept all these matters in hand. While we might shudder to think where the subject may lead in the next seventeen years we look with confidence to Unsöld to sort it all out and keep it into one connected argument.

The quantitative theoretical study of Fraunhofer lines began about 1927 and Unsöld contributed to the birth of this subject, which is really the central theme of astrophysics, by two important papers in the *Zeitschrift für Physik.* Using theoretically and experimentally determined atomic absorption of sodium in the Schwarzschild equation of transfer, and from profiles of D-lines observed by himself, he estimated the number of atoms above a bounded photosphere. These papers set a standard for the quantitative attack on the line intensity problem that has had its influence on developments since that time.

In 1930 he showed that the ionizing of hydrogen would have a profound effect on the stability of the Sun's atmosphere. He deduced that in the depth zone where hydrogen was partially ionized there would be convective movements which might readily explain the observed granulation of the solar surface. The calculation of the precise extent of the convective zone is no simple matter, and eighteen years after the first pronouncement of the effect we find Unsöld developing thermodynamical arguments to assist with this problem. However Unsöld's original explanation of the cause of convection has been accepted from the beginning. Thanks to this work we now know the reason for one of the driving forces that produce the varied phenomena known as solar activity.

The next major step forward (1932) was Unsöld's *weight function* method of computing the intensities of faint Fraunhofer lines or the wings of strong ones. The study of faint lines is simplified by the fact that the amount of darkening within the line is proportional to the line absorption coefficient. However the darkening still depends on the depth at which the line absorption occurs and this may vary very greatly from one line to another. The *weight function* method enables us to interpret the quantitative measurement of the intensity of a Fraunhofer line provided we can deduce how the absorption is distributed with depth. It is therefore the basis of very general methods for deducing the abundance of elements from Fraunhofer line intensity measurements.

From what has been said Unsöld's next requirement is fairly evident. In order to interpret spectra in detail one requires a complete picture of the physical conditions of the relevant stellar atmosphere. These conditions will need to be expressed in terms of well understood quantities such as temperature, density, pressure, electron pressure, etc., and the variations of all of these throughout the depth of the atmosphere. In 1934 Unsöld developed an analysis for this purpose. The accuracy of the resulting values depends on a sound interpretation of many physical data and a sound intuition for selecting certain constants such as the ratio between hydrogen and other elements. Unsöld led up to this problem by studies of such matters as the continuous absorption coefficient and then produced tables of the structures of atmospheres of the Sun and Red Giant Stars. This early work has set an example which has been followed in later years.

The most direct quantitative result from a study of stellar line intensities is a determination of the number of atoms in the stars' atmosphere and thence the chemical composition. Applying himself energetically to this problem Unsöld made extensive analyses of the spectra of the Sun's atmosphere, a solar prominence, and the Bo Star τ Scorpii. In the case of τ Sco he used his own observations of line intensities from spectra obtained at the McDonald Observatory, and the work remains the standard on which we base our knowledge of early star atmospheres.

Unsöld has made a full treatment of many of the more mathematical and physical researches that are required for astrophysics. We find among his papers, and those of his associates, discussions on : the continuous absorption of the material of stellar atmospheres; the effect of various types of collisions on spectral lines; cosmic rays; applications of the quantum theory; the equations of radiative equilibrium; nuclear physics; and thermodynamics. It is natural also that he has given much attention to the problems set by recent observations of radio astronomy.

He has had a long connection with the *Zeitschrift für Astrophysik*, being in fact the first contributor and the present editor. In Kiel he has built up a most flourishing school of theoretical astrophysics and experimental physics which is adding to and expanding the valuable work he does himself.

We are glad to hear that Unsöld has agreed to give a George Darwin Lecture on 1957 November 8 and we look forward to giving him a welcome in this Meeting Room at that time and also presenting him with the Gold Medal.

THE PRESIDENT'S ADDRESS ON THE AWARD OF THE JACKSON-GWILT MEDAL AND GIFT TO MR. R. P. DE KOCK

Professor Sir Harold Jeffreys

The Council has awarded the Jackson–Gwilt Medal and Gift to Mr R. P. de Kock for his systematic observation of variable stars over a period of more than 20 years.

Since 1933 he has sent observations regularly to the American Association of Variable Star Observers. He has now sent over 70 000 observations ; since 1946 his minimum per year is 4641 and his maximum 6666. He observes about 180 long-period variables, too far south to be observed from the northern hemisphere, and he tries to observe these stars at intervals of about 5 days during the time when they are far enough above the horizon to be observed against a dark sky. This involves observations in the evening and also for two or three hours before dawn.

In 1941 he discovered a new comet (1941 a) near one of his variable stars. He is a computer at the Cape Observatory, and is also largely responsible for the daily photography of the Sun. His observation of variable stars is done in his own time and not as part of his official duties.

An important feature of his work is that he reports his observations regularly to the A.A.V.S.O. They are combined with others to give mean light curves, and these are used to predict the dates of maxima and minima for the next year.

AN ADDRESS BY THE PRESIDENT

PROBABILITY THEORY IN ASTRONOMY

Professor Sir Harold Jeffreys

Probability theory goes back at least to Leibniz and to James Bernoulli, who is responsible for the important theorem known as the law of large numbers. Like all other subjects, however, its foundations need occasional re-examination. It was Bayes and Laplace in the eighteenth century who first attempted to use it to give a formal account of the process of learning from experience itself. They did not get far, but they did make a start. Pure mathematics itself was found by Cantor to need a complete overhaul, which has been largely carried out by Peano, Frege, Whitehead and Russell, Gödel, and Carnap, the last three of whom are still active. In pure mathematics we state a set of postulates at the outset, and show that whenever these hold some stated consequences follow. In learning from experience the procedure is not so clear. The set of observations relevant to any hypothesis is always finite, but the hypothesis, if it is to be called a scientific law at all, is held to be applicable to possible observations at other times or places, often to an infinite set. We are not concerned with deductive proof, except sometimes as an extreme case ; we need a theory of partial proof, or induction. The first thing we need is a notation. The early workers supposed that we can express the relation by fractions from 0 to 1 ; later ones have tried to give some metaphysical reason why we must do so, and others have pointed out difficulties in the application of these reasons and consequently proposed restrictions on the applicability of the theory. The explanations and the restrictions are equally pointless. The notation is simply a way of expressing a logical relation that we cannot escape using if we are to make any progress at all, but which falls short of deductive proof or disproof. The notation that I find far the most convenient is

$$P(q \mid p) = a, \tag{1}$$

read, " The probability of q, given p, is a ", where p and q are two sets of propositions and $0 \leqslant a \leqslant 1$. If p entails q, $a = 1$; if p contradicts q, $a = 0$. To get a useful theory we need rules for assigning a. The two chief are the addition rule : if q, r cannot both be true given p, then

$$P(q \text{ or } r \mid p) = P(q \mid p) + P(r \mid p) : \tag{2}$$

and the product rule

$$P(q \text{ and } r \mid p) = P(q \mid p) P(r \mid q \text{ and } p). \tag{3}$$

The addition rule leads directly to Laplace's rule for calculating probabilities of sets of equally probable alternatives. The product rule is often taken to read " The joint probability of two propositions is the product of their probabilities taken separately " ; that is

$$P(q \text{ and } r \mid p) = P(q \mid p) P(r \mid p). \tag{4}$$

This is obviously wrong. We might have $r = \text{not } q$, with $P(q \mid p) = P(r \mid p) = \frac{1}{2}$. Then this equation reduces to

$$0 = \tfrac{1}{4}.$$

The correct formula gives $0=0$, since, given q and p, not q is impossible and hence $P(r \mid q \text{ and } p)=0$. Note however that without a notation that states the data explicitly we could not distinguish between (3) and (4); and many writers still do not use such a notation.

The product rule leads at once to the principle of inverse probability: if p is our previous knowledge, $q_1, q_2, \ldots q_n$ a set of hypotheses, and θ a set of observed data,

$$P(q_r \mid p\theta) = AP(q_r \mid p)P(\theta \mid q_r \text{ and } p) \tag{5}$$

where A is independent of r. It can be read: the posterior probability of a hypothesis is proportional to the product of the prior probability and the probability of getting the data, given the hypothesis and the previous information. It explains at once the importance of the "crucial test", where θ is very likely if q_1 is true but not if any of $q_2 \ldots q_n$ is true; in such a case, if the prior probabilities are not very different, $P(q_1 \mid p\theta)$ will be very large in comparison with the others and therefore will be nearly 1.

This however is not enough. In an actual case the previous information p will usually include a lot of observational evidence, and somebody might ask "what were the probabilities before you had that evidence?" By repetition he can push us back to a position where we have to assess probabilities on no observational evidence at all. All the information we have is the general principles of the theory. Call these H. One important principle now stands out. We are looking for a system that will in suitable cases attach probabilities near 1 to a law. But the laws we have to consider at the outset may be infinite in number, and if they are all equally probable the initial probability of each must be zero. But then the posterior probabilities of laws are proportional to a lot of numbers each containing a zero factor and therefore are totally indeterminate. We could make no progress at all. The way out is obvious enough when the problem is stated. Even on no observational information at all, we can take the probabilities of laws all positive. They can form the terms of a convergent series of sum 1, such as $\Sigma 2^{-m}$. At this point the notion of simplicity enters. We do in fact try a simple law first, say that our observed quantity is constant. If this fails we try a linear variation; if this fails we try a quadratic form, and so on. For any law expressible by a differential equation and therefore any law of classical physics, we can attach a definite number to the complexity of the law and assign its place in the initial probability sequence. Since quantum laws are found by an automatic process from classical ones, the same will apply to them.

Most laws, however, are not predictions of exact values. If we regarded the law of gravitation, for instance, as concerned only with exact values, we could fit the observations of the planets exactly by suitable orbital elements—provided there are not too many of them. But beyond a certain number of observations ($7n$, where n is the number of planets) we cannot get an exact fit. Error of observation comes in. The actual value of the error at each observation is unpredictable, and we have to do our best about it. Elementary ideas of exact prediction break down altogether, as Laplace knew perfectly well, and it is amazing that when Heisenberg proposed an indeterminacy principle in quantum theory it was hailed by philosophers and many physicists alike as something revolutionary. Any law, for practical application, must be

stated in such a way as to state probabilities of error of different amounts. This calls for a complete reversal of classical determinism. We do not try to predict exact observed values. Any process starts with random variation as a primitive idea ; as we proceed we find that more and more of the actual variation can be explained as calculable from other information. Thus actual scientific method consists of successive approximations to probability distributions. Its connection with what philosophers call reality is a further question, but I think not an important one scientifically.

The theory leads to rules of significance for the introduction of new parameters in laws. They are usually approximately of the form

$$K=\frac{P(q\,|\,\theta p)}{P(q'\,|\,\theta p)}\doteqdot(An)^{1/2}\exp\left(-\frac{a^2}{2s_a^2}\right).$$

Here q is the hypothesis that the new parameter α is zero, that is, that the previous law needs no alteration ; q' the hypothesis that α is needed, having a value to be estimated from the observations ; a and s_a are the estimate of α and its standard error as given by the method of least squares ; n is the number of observations ; and A is a constant, usually not far from 1. If $|a|<s_a$, the factor $n^{1/2}$ makes $K>1$ and the old law is supported ; but with ordinary numbers of observations, if $|a|>2s_a$ or $3s_a$, $K<1$ and the new law is supported. To apply a test of this sort it is of course of the first importance that the number of observations shall be stated. This is in fact not often done by physicists, but thanks mainly to the work of Fisher (with whom I do not always agree) biologists usually do it, but with different rules.

For many purposes a rougher test suffices, namely Pearson's χ^2. If we have n independent determinations, say $x_r\pm\sigma_r$,

$$\chi^2=\Sigma\frac{x_r^2}{\sigma_r^2}.$$

Its expectation is n, and it normally lies between $n\pm\sqrt{2n}$. If m parameters are adjusted to fit the data and the calculated values a_r corresponding to them are found, we can take

$$\chi^2=\Sigma\frac{(x_r-a_r)^2}{\sigma_r^2}$$

instead ; and this follows the same rules with n replaced by $\nu=n-m$. It is only when χ^2 lies outside the range $\nu\pm\sqrt{(2\nu)}$ that we usually need a more sensitive test.

I should say that statisticians generally hold that probabilities refer only to observations given a hypothesis, and regard probabilities of hypotheses given the observations as meaningless. If anybody uses observations to help him to decide what hypothesis is true, statisticians usually do not forbid him, but take no responsibility. This is, I consider, simply shirking what we, as scientists, need to know.

At this point I wish to say something about a common attitude of astronomers and still more of experimental physicists. For most purposes a set of data can usually be summarized by the estimates of the parameters, their standard errors, and the number of estimated degrees of freedom (number of observations less the number of parameters). But it is still widely believed that a standard error is a final statement of accuracy. This is not so. In the first place it

rests on a hypothesis that the outstanding variation is random, that is, that subject to the standard error, the value of the errors at previous observations give no additional information about that at a new one. This can break down in two ways. The conditions of observation may be such that a part of the error would be predictable for all observations, given its value at one observation. This is what we usually call systematic error. If systematic error is present, we cannot reduce the error of the estimate below a certain amount, however many observations we make. However, this fact does not dispose of the need to state the standard error given by the observations. If we are ever to trace a systematic error we must either detect it from comparison with other observations, which can be done by a significance test, or find a way of calculating it. In either case the standard error still has an important part to play. But in fact it is often suppressed and replaced by an uncertainty based on "judgment", which I should prefer to call guesswork. The experimenter thinks he knows how accurately he is working and states limits of error accordingly. There is a widespread belief that these are wider than the standard error; this does not agree with my experience. The stated uncertainty is sometimes several times the standard error, but I have had cases where it was as low as a tenth of the standard error.

There is however a more subtle kind of departure from randomness, which Newcomb called a semi-systematic error and is now included in what are called stochastic processes. It is related to what I have called internal correlation, and to what Fisher calls intraclass correlation. Karl Pearson made an important study of this in two series of experiments designed to imitate the measurement of the right ascension and declination of a star with a transit circle, with special reference to the observers' personal equations. These have usually been treated as true systematic errors. Pearson found that this is not so. He had a series of about 500 measures by each observer, and took them in groups of 25. If the standard error found from the whole series is taken as 1, the means of 25 should show a variation consistent with a standard error of 1/5. They actually always exceeded this, in some cases by a factor of 3. Constant systematic error is eliminated by this method of comparison; what is shown is that there is a variable part of the error which tends to repeat itself over several consecutive observations. It is possible to make a test for this, and it should be applied whenever possible.

Errors of this type are a major nuisance, because the whole theory of the method of least squares depends on the postulate of independence of the errors (always given the standard error). There are techniques for dealing with them in some cases. Often they can be detected, as in Pearson's case, by comparing groups of observations, and the group estimates will then lead to a better estimate of uncertainty. Sometimes, as in the variation of latitude, the departure from randomness is a fundamental part of the whole process, and a much more elaborate technique is needed. There are problems where, even if the errors were originally random, correlation between them is introduced by the method of comparison. Suppose $y=0$ for all values of x, and we use only integral values of x. If for $x=0$ we take $y=1$ instead, and then use any interpolation formula, the interpolated y will be positive between $x=-1$ and $+1$, and negative between -2 and -1, and between $+1$ and $+2$. In general if y at integral x are independent errors of observation, the interpolated y will be correlated. If a second set of observations, not at integral x, are compared

with the interpolated y, the residuals will have a correlation. My analysis of Spencer Jones's data on the lunar equation treated this type of correlation, which in this case could be estimated and allowed for. We also have cases where the observed values, known to have errors, have to be used to construct a table ; the problem is to smooth them, reducing the errors, as far as possible, without introducing systematic error. Often the theoretical function is known except for adjustable parameters, and then the method of least squares succeeds. But sometimes no such function is known ; what can be done ? A method that I found satisfactory in constructing the seismological tables is as follows. We classify the observations in ranges. In each range we can fit a linear form by least squares. We could also fit a quadratic form, and the two coincide at two values with the range. It is found that at these two values the errors are independent. Hence if we use the linear solution to determine the values of y for these two values of x, they will be more accurate than the original values, their errors are still independent, and they are not affected by a square term if there is one. I call these ***summary values***. They can then be used to interpolate a complete table by divided differences. In the process we might smooth out a real irregularity, but this can be checked by computing χ^2 for the original values against the interpolates.

In view of the importance of E. Rabe's results on the masses of the inner planets and the solar parallax derived from perturbations of Eros, I have applied such a test to his data. The stated uncertainties are based on the hypothesis that the errors are completely random. I took means of consecutive observations by threes and derived a test for persistence of error. This was particularly desirable in this case since the data had been reduced to Universal Time, and an error in this reduction would produce such persistence. However the test showed that there was evidence against it ; Rabe's uncertainties are probably valid, and it would go beyond reasonable pessimism to multiply them by more than 1·5.

H. E. Hertz has recently given a determination of the mass of Saturn from perturbations of Jupiter, which looks extremely accurate. He had four series of observations with properly determined uncertainties, but in combining them he used weights based on judgment. A simple test, however, showed that the actual variation was perfectly consistent with random variation according to the apparent uncertainties, and it would have been better to use these. When this is done the change in the estimated mass is small, but not inappreciable.

Perhaps the most striking example of what may be an effect of inflated uncertainties is to be found in Eddington's later work. He used three experimental values of physical constants to infer values of 15 others. These all agreed with experiment within the " probable error " ; that is, a chance of 1 in 2^{15} came off ! I am not going to say whether Eddington's theory is right or not ; but I must remark on the extreme naïveté of his acceptance of such a result without comment.

My point is that the formal standard error may for various reasons be an underestimate of uncertainty, but it always has the right to speak in its own defence.

Some years ago I was looking for a probability problem that did not concern the question of inference from observation to hypothesis, and I chose the kinetic theory of gases. I expected current theory to be right, and was astonished to

find that it was wrong in a most elementary point, namely, the use of the wrong form of the product rule. In Boltzmann's H-theorem a probability law of general form is written down for the positions and velocities of a molecule. The joint probability for those of two molecules is derived by simple multiplication. The joint probability after collision is then derived, and shown to be nearer the Maxwellian distribution than the previous one. But multiplication of the probabilities for two molecules before collision is legitimate only if these probabilities are independent. The argument is like saying that in a population where half the people have blue left eyes and half have brown right eyes, there is probability $\frac{1}{4}$ that the next individual we meet will have a blue left eye and a brown right eye. In a gas admitted to a chamber the velocities are originally away from the orifice, and if one molecule has a velocity away from the surface there is an excess of probability that a neighbouring one will have one too. Thus the argument is quite invalid as an explanation of the tendency to a Maxwellian distribution.

The alternative approach of Gibbs is no better, since it postulates an infinite set of assemblies of molecules and considers ratios of numbers of subsets. Apart from the fact that ratios of infinite numbers are meaningless, it treats all assemblies together, and still fails to show how a newly disturbed gas can settle down.

I find in fact that probability theory does lead to the required explanation, though I cannot develop this here. The main point is that energy in any coordinate, in the conditions of a gas, and given enough time, has a non-zero probability of being transferred to any other. Given this, we can establish the rule that the expectations of energy in all components approach equality. This is the law of equipartition. But the argument depends quite essentially on this notion of unrestricted possibility of transfer. This has been proved directly in many dynamical problems, and classical statistical mechanics depends on it ; where it has not been proved or disproved it is still worth while to assume it and develop its consequences and see whether they agree with experiment.

However, the whole argument breaks down if there are limitations on the possibility of transfer, and there are two problems of interest to astronomers where it has been misapplied. I take first Jeans's theorem on statistically steady motions where mutual attractions can be neglected. In this case no means of energy transfer is provided. Jeans's argument shows only that if steady motion exists, the probability density is constant along an orbit ; but he mistakenly supposed that this implies that it is a function of the algebraic first integrals, whereas it might be any function of the orbital elements.

The other is of still greater importance. Rayleigh applied the rule of equipartition to radiation in an enclosure, and found that it implied that the energy between frequences ν and $\nu+d\nu$ is $A\nu^2 d\nu$, where A is a constant. This disagreed with experiment for large ν ; further, it implies that for a given total energy $A=0$, and hence there can be no steady state—again contrary to experiment. Now the remarkable thing is that Rayleigh's rule was thought—and is still thought—to be a deduction from classical physics. It is not. The equations of the electromagnetic field are exactly linear, and energy in one normal mode must stay in that mode. In classical physics every distribution of radiant energy between wave-lengths is a steady state. The enclosure in the theory was taken as perfectly reflecting, and interaction between the radiation and the

molecules of an actual boundary might lead to transfer of energy, and it is at this point that the experimental result is relevant. Since equipartition gives too much energy at high frequencies there must be something that prevents free interchange of energy at high frequencies even with a natural boundary. Applying this result to gases suggests at once an explanation of why the rotations of the atoms did not appear to contribute to the specific heats—in equipartition they would have to be frightfully fast ; and this *is* a case where equipartition follows from classical physics. Somehow physicists did manage to develop quantum theory, but I strongly suggest that they would have done so much sooner if proper attention had been given to probability theory when the kinetic theory of gases was founded. At the present time, when probability considerations are held to arise in the most elementary interactions, the need for such attention is greater than ever.

APPENDIX

A test of Rabe's uncertainties.—The data* are 37 pairs of residuals, arranged in order of time, in R.A. and declination. 16 unknowns are estimated from the equations of condition. The question is whether there is any evidence of persistence of errors, which might vitiate the hypothesis that the errors are independent. The procedure adopted was first to take the residuals after adjustment of the unknowns and determine standard deviations ; and then to form means by groups of three and derive revised standard deviations from these. Provisionally each series was taken as on $37-8=29$ degrees of freedom ; then the first results were :

	Sum of squares	s_1
$\Delta\alpha \cos\delta$	$200\times 10^{-4}(1^s)^2$	$0^s{\cdot}026$
$\Delta\delta$	$3{\cdot}04\ (1'')^2$	$0''{\cdot}32$

If the observations in α and δ are equally accurate, $0^s{\cdot}026$ in $\alpha\cos\delta$ would correspond to $0''{\cdot}39$ in δ, and there is no reason to infer a difference. Assuming this we are led to a combined uncertainty $s_1=0''{\cdot}36$ on 58 degrees of freedom.

The means by threes (except that the last group contains four) are 12 in number for each series and lead to

	Sum of squares	s_2
$\Delta\alpha \cos\delta$	$1820\times 10^{-6}(1^s)^2$	$0^s{\cdot}021$
$\Delta\delta$	$0{\cdot}2697(1'')^2$	$0''{\cdot}26$

where the estimates are provisionally taken as on 4 degrees of freedom. For independent errors the ratio of s_1, s_2 would be expected to be about $\sqrt{3}$ to 1 ; there is a reduction, but not in such a ratio, and the question is whether the difference is significant. Combining the results on the basis of $15''$ to 1^s gives $s_2=0''{\cdot}291$ on 8 degrees of freedom. Direct comparison of s_1 and s_2, however, does not give a satisfactory test, because the variation used to determine s_2 is included in that used for s_1. We must subtract the 3-data means from the residuals and form a new sum of squares, now based on $50(=74-24)$ degrees

* E. Rabe, *A.J.*, 55, 112–126, 1950.

of freedom ; this leads to $s_3 = 0''\cdot338$. If the hypothesis of independence is correct this would correspond to

$$s_2 = 0''\cdot338/\sqrt{3} = 0''\cdot195 \quad 50 \text{ d.f.}$$

and the question is whether this is consistent with the direct estimate

$$s_2 = 0''\cdot291 \quad 8 \text{ d.f.}$$

This can be answered from a rule given in my "Theory of Probability" ([10], p. 257) :

$$K \doteqdot \left\{\frac{\pi n_1 n_2}{2(n_1+n_2)}\right\}^{1/2} \frac{\cosh 2z}{\cosh z} e^{n_1 z} \left(\frac{n_1+n_2}{n_1 e^{2z}+n_2}\right)^{\frac{1}{2}(n_1+n_2)}$$

$$\doteqdot \left\{\frac{\pi n_1 n_2}{2(n_1+n_2)}\right\}^{1/2} \left(1+\frac{3}{2}z^2\right) \exp\left(-\frac{n_1 n_2 z^2}{n_1+n_2}\right)$$

where e^z is the ratio of the two estimates of the standard error. In this case $z = 0\cdot400$; the first formula, which is the more accurate, gives $K = 1\cdot08$, the second $K = 1\cdot36$. $K > 1$ means that there is support for the hypothesis of independence. Here K is not much above 1. The conclusion may be stated (1) that available evidence is slightly in favour of the hypothesis that there is no persistence of errors, and consequently that Rabe's uncertainties are valid ; and (2) the evidence is far from decisive, and the hypothesis that there is some persistence of errors is not finally disposed of ; but there would be no basis for multiplying the uncertainties by more than a factor $0\cdot291/0\cdot195 = 1\cdot49$.

*Hertz's determination of the mass of Saturn**.—This is given as

$$1/(3497\cdot64 \pm 0\cdot27) \text{ (p.e.)}$$

from perturbations of Jupiter. This is based on the following reductions : each set of data is compared separately with Hill's orbit and one found by numerical integration. The stated uncertainties are probable errors.

Set	Hill	Integration
1	3497·14 ± 0·51	3497·98 ± 0·48
2	5·90 ± 0·45	6·23 ± 0·42
3	6·67 ± 0·67	7·80 ± 0·58
4	8·07 ± 0·78	8·68 ± 0·82
5	6·58 ± 0·31	7·22 ± 0·28
6	6·96 ± 0·28	7·64 ± 0·27

Set 5 is a simple mean of sets 1, 2, 3, and set 6 is a mean of sets 1, 2, 3, 4, the last with weight $\frac{1}{3}$. Thus no summary that includes either or both of these sets rests on independent data. The straightforward procedure is simply to combine the data with weights according to the estimated probable errors, and ignore the combinations 5 and 6. The means are then for Hill's orbit $3496\cdot69 \pm 0\cdot28$, and for the integration orbit $3497\cdot34 \pm 0\cdot27$. These give the following computation of χ^2.

Set	Hill			Integration		
	Weight	O−C	w(O−C)^2	Weight	O—C	w(O−C)^2
1	4	+0·45	0·8	4	+0·64	1·8
2	5	−0·79	3·1	5·3	−0·81	3·7
3	2·2	−0·02	0·0	3·0	+0·46	0·6
4	1·6	+1·38	3·1	1·5	+1·32	2·6
	12·8		7·0	13·8		8·7

* H. E. Hertz, *Astr. Pap. Amer. Ephemeris*, **15**, 171–215, 1955.

Since w is based on probable errors, which are $\frac{2}{3}$ of the standard errors, the respective χ^2 are

$$\tfrac{4}{9}\times(7\cdot0,\ 8\cdot7)=(3\cdot1,\ 3\cdot9).$$

These are quite normal on 3 degrees of freedom. Thus the sets 1, 2, 3, 4 are perfectly consistent and there was no need for further adjustment. The first striking point is that Hertz's adopted $1/m$ is higher than either of the simple estimates, the second is that the difference between the values based on Hill's orbit and the integration orbit is 0·65, more than twice the probable error of either. This difference represents only an incompleteness of arithmetic in one or other calculation, and cannot be treated by probability theory. It is, however, a valuable example in showing how, as observations accumulate and improve, more and more accurate calculation is needed to make the best use of them.

From the satellites I have estimated* the mass ratio

$$\text{Sun/Saturn}=3494\cdot04\pm1\cdot11\ \text{(s.e.)}.$$

Here the chief datum is from Iapetus, so that this mass of Saturn effectively includes that of Titan, and the result should be directly comparable with the perturbation value. The difference is 2·65 or 3·30, and decidedly large in relation to the uncertainties. It could however be due to an error of 1 in 3000 in the micrometer measures, which is not out of the question.

If we accept the comparison with the integration orbit, and convert to standard error, we have

$$\text{Sun/(Saturn + satellites)}=3497\cdot34\pm0\cdot40.$$

* *M.N.*, **114**, 435, 1954.

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